TP 14647E

Development, Implementation and Testing of an Advanced Transit Communications and Location System

Prepared for
Transportation Development Centre
of
Transport Canada

by
City of Winnipeg Transit System

September 2005

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2007-01201/

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Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

Un sommaire français se trouve avant la table des matières.

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.	2. Project No.	3. Recipient's Catalogue No.
TP 14647E	5328-5329	

4. Title and Subtitle	5. Publication Date
Development, Implementation and Testing of an Advanced Transit Communications and Location System	September 2005
	6. Performing Organization Document No.

7. Author(s)	8. Transport Canada File No.
Keith D. Martin	2450-GP001

9. Performing Organization Name and Address	10. PWGSC File No.
City of Winnipeg Transit System 421 Osborne Street Winnipeg, Manitoba, Canada R3L 2A2	MTB-2-01614
	11. PWGSC or Transport Canada Contract No.
	T8200-022533/001/MTB

12. Sponsoring Agency Name and Address	13. Type of Publication and Period Covered
Transportation Development Centre (TDC) 800 René Lévesque Blvd. West Suite 600 Montreal, Quebec H3B 1X9	Final
	14. Project Officer
	Brian Marshall

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

Co-sponsored by the Program of Energy Research and Development (PERD) of Natural Resources Canada (NRCan).

16. Abstract

The primary objective of the Winnipeg Transit project was to develop an urban transit "smart bus" platform, one capable of autonomously determining real-time schedule adherence, in order to be the foundation for a wide range of ITS applications supporting transit operations, planning and customer service functions. The project integrated a number of on-board components, including global positioning (GPS) and automatic passenger counting (APC) equipment, schedules database, radio and controller/modem, and driver interface unit (DIU). On-board schedule adherence determination allows for exception reporting of schedule deviations to a central computer, minimizing the amount of radio bandwidth/channels required for determining real-time system-wide schedule performance. Other objectives included the capability for two-way text messaging between central control and buses, and bus-to-bus data messaging/notification.

Test results showed that on-board schedule adherence, with exception reporting, is an efficient and reliable means of supplying real-time schedules information. The "smart bus" can provide accurate and timely schedule adherence information to bus operators, to supervisory staff, and to customers through connected telephone and internet information systems. The smart bus also enables other ITS technologies such as on-board automated next stop enunciation and traffic signal priority only for late buses. Text messaging to buses reduces the requirement for voice communications and improves information distribution. Bus-to-bus data messaging can support such things as transfer passenger notifications.

17. Key Words	18. Distribution Statement
Urban Transit, Global Positioning System (GPS), Automatic Vehicle Location (AVL), Real-time Schedule Adherence, Driver Interface Unit (DIU), Intelligent Transportation Systems (ITS), Smart Bus	Limited number of print copies available from the Transportation Development Centre. Also available online at www.tc.gc.ca/tdc/menu.htm

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	—	xx, 72	Shipping/ Handling

Transports Canada / Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada	2. N° de l'étude	3. N° de catalogue du destinataire
TP 14647E	5328-5329	

4. Titre et sous-titre	5. Date de la publication
Development, Implementation and Testing of an Advanced Transit Communications and Location System	Septembre 2005
	6. N° de document de l'organisme exécutant

7. Auteur(s)	8. N° de dossier - Transports Canada
Keith D. Martin	2450-GP001

9. Nom et adresse de l'organisme exécutant	10. N° de dossier - TPSGC
City of Winnipeg Transit System 421 Osborne Street Winnipeg, Manitoba, Canada R3L 2A2	MTB-2-01614
	11. N° de contrat - TPSGC ou Transports Canada
	T8200-022533/001/MTB

12. Nom et adresse de l'organisme parrain	13. Genre de publication et période visée
Centre de développement des transports (CDT) 800, boul. René-Lévesque Ouest Bureau 600 Montréal (Québec) H3B 1X9	Final
	14. Agent de projet
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15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Coparrainé par le Programme de recherche et développement énergétiques (PRDE) de Ressources naturelles Canada (RNCan)

16. Résumé

Le projet de Winnipeg Transit avait pour objet principal de développer une plate-forme d'«autobus intelligent» de transport urbain, capable de contrôler de façon autonome, en temps réel, le respect de l'horaire, ouvrant ainsi la voie à toute une gamme d'applications STI à l'appui des services d'exploitation et de planification, et des services à la clientèle d'une société de transport en commun. Le projet a consisté à intégrer divers composants à bord du véhicule, soit un GPS (système de positionnement global), un système de dénombrement automatique des passagers (DAP), la base de données des horaires, une radio et un contrôleur/modem, et une interface conducteur (IC). Comme le contrôle du respect de l'horaire se fait à bord de l'autobus même, seuls les écarts par rapport à l'horaire sont signalés à un ordinateur central, ce qui réduit le nombre de bandes de fréquences/la largeur de bande radio nécessaire pour avoir un tableau en temps réel du respect des horaires dans tout le réseau. Parmi les autres objectifs assignés au projet figuraient la fonction de messagerie texte bidirectionnelle entre le centre de commande et les autobus, et la messagerie de données/notification entre autobus.

Les résultats des essais ont révélé que le contrôle du respect de l'horaire à bord de l'autobus même, avec le signalement des écarts par rapport à l'horaire, est un moyen fiable et efficace de communiquer en temps réel l'information sur les horaires. L'«autobus intelligent» peut indiquer de façon précise et immédiate aux exploitants, aux surveillants et à la clientèle s'il respecte son horaire, par téléphone ou par Internet. L'autobus intelligent ouvre aussi la voie à d'autres technologies STI, comme l'annonce automatisée du prochain arrêt et l'activation des signaux de priorité uniquement pour les autobus qui sont en retard. La messagerie texte réduit le besoin de communications phoniques et améliore la diffusion de l'information. Quant à la messagerie de données entre autobus, elle peut appuyer des fonctions comme la notification de passagers en correspondance.

17. Mots clés	18. Diffusion
Transport urbain, Système de positionnement global (GPS), Localisation automatique de véhicules (AVL), Contrôle en temps réel du respect de l'horaire, Interface conducteur (IC), Systèmes de transports intelligents (STI), Autobus intelligent	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires imprimés. Disponible également en ligne à www.tc.gc.ca/cdt/menu.htm

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	xx, 72	Port et manutention

ACKNOWLEDGEMENTS

The cooperation of the operations and maintenance staff of Winnipeg Transit, as well as the staff of the Corporate Communication Systems Branch is gratefully acknowledged. The advice and support of Catherine Hirou and Brian Marshall, Transportation Development Centre of Transport Canada are also recognized.

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EXECUTIVE SUMMARY

The Advanced Transit Communications and Location System Project was undertaken by Winnipeg Transit, with Infodev Electronic Designers Inc. as a sub-contractor, and financial support provided by the Transportation Development Centre, Transport Canada. The primary objective of the Project was to develop an urban transit "smart bus" platform, one capable of autonomously determining real-time schedule adherence, in order to be the foundation for a wide range of ITS applications supporting transit operations, planning and customer service functions. The approach was to develop and test a transit communications system that includes an AVL capability and that performs schedule adherence calculations locally on-board each vehicle and transmits information to a central computer for only the buses that are not operating within a designated tolerance of the planned schedule.

Since most buses operate within planned tolerances, this approach would reduce the amount of data to be transmitted to the central Transit Control Centre, thereby minimizing the investment that might otherwise be required in radio infrastructure or other wireless technology to support the real-time flow of data for a fleet size of 535 buses. It would also allow for continuous schedule feedback to the bus operator without interaction with the Control Centre. Most importantly, having real-time schedule adherence intelligence on-board each bus supports such ITS applications as automated next stop enunciation, as well as selective traffic signal priority only for those buses operating behind schedule.

A unique public-private partnership existed between Winnipeg Transit and Infodev. Infodev is a leading international supplier of APC systems for various applications and had supplied Winnipeg Transit with a system for 73 buses. Infodev had extensive experience with GPS, electronic design, data logging, and radio technologies. Winnipeg Transit had substantial experience with the existing bus radio control system and incident management applications, which it had custom developed, as it had also done with several other pillar operating systems. Winnipeg Transit had also invested considerably in database development for the APC project, which would otherwise be necessary in the AVL project and could therefore be leveraged effectively. Finally, the City of Winnipeg's Communications Systems Branch could also provide broad expertise in radio technology, both voice and data.

As part of this Project, Winnipeg Transit wished to retain the use of the existing radio frequencies for which it was licensed and the repeater tower installations that it owned, but there was an urgent need to replace all aging on-board and base signalling radio equipment with modern hardware and software. Winnipeg Transit required seamless integration of the new radio technology and new advanced functions, while continuing to support the existing radio system, both during the prototype demonstration and when considering fleet-wide implementation.

The Project involved the development and testing of such a system on 10 of the 73 buses already instrumented with automatic passenger counting (APC) equipment, which includes a global positioning (GPS) antenna and receiver, infrared transceiver, and on-board data logging computer. The project approach was premised on the knowledge that additional units of this type could be supplied and installed at a cost that would make fleet-wide use of AVL economically practical for Winnipeg Transit.

Work on the Project began in 2003 with the development of a new on-board radio controller and replacement of the radio, handset and hands-free microphone used for emergencies. Next a driver interface unit (DIU) was developed that used a visual display screen and was capable of flexible reconfiguration. These components were interfaced together and offered backward compatibility by supporting existing radio communications with the Control Centre. Testing over many months demonstrated they were reliable and rugged and the DIU was user friendly.

Concurrent with the upgrading of on-board radio equipment, a modern replacement for the base signalling unit (BSU) housed at the radio repeater towers was also developed. The BSU relays data messages between buses and the Control Centre's computerized radio control system. The new BSU was designed to support existing voice communication functions with the newly re-equipped test buses, and also to support new data message types that would be required for the schedule adherence system and other planned advanced functions, such as text messaging.

The development of the on-board schedule adherence system began with Infodev creating a technique for compressing a complete master schedule file for a seasonal booking period, to the point that it is feasible to upload a complete schedule for every route/run into the available memory of the data logging microprocessor on all buses. This provides the greatest flexibility in determining or changing the work assignments of buses during the course of the day. A method and technology for transferring the schedule data onto the buses was developed using Radio Frequency (RF) spread spectrum modems. RF technology was employed for the daily setting of the route/run value for the bus data logger, in order for it to decompress the correct schedule to follow. The data logger was also able to receive this instruction via the bus radio system, to permit the bus to be re-assigned during the day and the run value to be changed accordingly.

Each route/run has several locations designated as "timing points" for scheduling purposes. These are typically at the ends of the route and at significant stops along the way. On average there is approximately 10-15 minutes of running time between timing points, and a number of intermediate bus stops served. In the schedules database, each time point has latitudinal and longitudinal coordinates. The schedule adherence "engine" developed by Infodev uses the GPS inputs and a sophisticated algorithm to provide *actual* schedule deviation at timing points and *predicted* schedule deviation when between timing points.

The DIU is used to continuously display the schedule adherence information to bus operators to assist them in following their schedule. The deviation is shown in minutes and seconds, either as a positive number if the bus is ahead of schedule, or a negative number if the bus is behind schedule. The basic premise is to operate as closely as possible to a zero deviation.

Schedule deviation reports from the bus to the Control Centre, sent via radio, are generated automatically by the system when set parameters are exceeded. For Project testing purposes, the system was configured to send deviation reports if a bus was more than five minutes late or more than two minutes early, which reflected Winnipeg Transit operating protocols and reporting requirements for bus operators. Deviation reports can also be generated if the bus does not reach a timing point within a range of the expected time or distance, indicating the bus may be off-route or some other problem exists.

The Project also included the upgrade of the Control Centre communication control and incident management system to support real-time schedule adherence reporting. It was determined to be more practical to replace the existing CONTACT system, rather than attempt major modifications. Hence, Winnipeg Transit undertook development of the new Intracom system. Intracom would provide a more reliable and robust communication and incident management tool for controllers. Intracom would be the focal point for processing and interpreting real-time schedule adherence information and supplying this to other traveler information outlets. Intracom was also designed for such advanced functions as:

- two-way text messaging with buses to reduce the reliance on voice communications and enhance information dissemination, retention and retrieval
- automated transfer notifications to support bus operators alerting other buses of transferring passengers
- autonomous data logging of routine events and occurrences for statistical purposes, e.g., bike rack usage
- intelligent "service visualization" and "service modelling" functionality to assist supervisory staff by analyzing wide-spread service disruptions and recommending modifications to restore service to normal operation

Testing of the on-board schedule adherence system demonstrated that it could very accurately determine the schedule performance of the vehicle, continuously display this to the operator and automatically report the exceptions via radio to the new Intracom system. Implementing a system of this nature would minimize the data traffic required to obtain real-time schedule information fleet-wide, making possible the use of existing radio channels/frequencies at no additional cost. The on-board equipment required can be compact, durable and supplied cost-effectively. The additional on-board intelligence can also then be used to support other peripheral devices, such as next stop enunciators, or for traffic signal light pre-emption for buses operating behind schedule. Larger transit systems may particularly benefit from employing this approach to address real-time vehicle location and schedule adherence.

SOMMAIRE

Le projet de Système évolué de communications et de localisation de véhicules a été réalisé par Winnipeg Transit de concert avec Infodev Electronic Designers Inc., à titre de sous-traitant, avec l'appui financier du Centre de développement des transports de Transports Canada. Le but premier du projet était de développer une plate-forme «d'autobus intelligent» de transport urbain capable de contrôler de façon autonome, en temps réel, le respect de l'horaire, ouvrant ainsi la voie à toute une gamme d'applications STI à l'appui des services d'exploitation et de planification, et des services à la clientèle d'une société de transport en commun. La démarche a consisté à développer et à mettre à l'essai un système de communications pour réseau de transport en commun doté d'une fonction de localisation automatique des véhicules (AVL), qui laisse chaque véhicule calculer ses écarts par rapport à son horaire, et transmet à un ordinateur central uniquement les données concernant les autobus dont l'écart dépasse certaines limites de tolérance établies.

Comme la plupart des autobus respectent les limites de tolérance établies, cette méthode entraîne une diminution du volume de données transmises au centre de commande, réduisant du coup les sommes qu'il faudrait investir dans une infrastructure radio ou une autre technologie sans fil s'il fallait assurer la transmission en temps réel de la masse de données concernant un parc de 535 autobus. De plus, grâce à cette méthode, les chauffeurs d'autobus savent en tout temps s'ils respectent leur horaire, sans que le centre de commande ait à intervenir. Mais, plus important encore, le fait que l'information sur le respect de l'horaire soit connue en temps réel à bord de chaque autobus ouvre la voie à des applications STI comme l'annonce automatisée du prochain arrêt et l'activation sélective des signaux de priorité, seulement pour les autobus qui sont en retard.

Un partenariat public-privé unique a été établi entre Winnipeg Transit et Infodev. Infodev, un important fournisseur international de systèmes de dénombrement automatique de passagers (DAP) destinés à diverses applications, avait déjà fourni à Winnipeg Transit de tels systèmes pour 73 de ses autobus. Infodev possédait une vaste expérience des systèmes de positionnement global (GPS), de la conception électronique, de la collecte de données et des technologies radio. Winnipeg Transit avait une grande expérience des systèmes existants de radiocommande et de gestion des incidents à bord de ses autobus, qu'elle avait développés pour ses propres besoins, comme elle l'avait fait pour plusieurs autres systèmes d'exploitation piliers. Par ailleurs, Winnipeg Transit avait beaucoup investi dans le développement d'une base de données pour le projet DAP. Or, le projet AVL nécessitait aussi une base de données, et la société avait là l'occasion de rentabiliser ses investissements initiaux. Finalement, la Direction des systèmes de communications de la Ville de Winnipeg était disposée à mettre à la disposition du projet son expertise poussée dans le domaine de la technologie radio, tant pour les communications en phonie que pour les transmissions de données.

À l'origine, Winnipeg Transit souhaitait continuer à utiliser, aux fins du présent projet, les radiofréquences pour lesquelles elle détenait une licence, ainsi que les émetteurs relais

qu'elle possédait déjà, mais il était urgent de remplacer tout l'appareillage radio et de signalisation vieillissant, de base et mobile, par des matériels et des logiciels modernes. Winnipeg Transit a dû assurer une intégration transparente de la nouvelle technologie radio et des nouvelles fonctions évoluées, en continuant à soutenir les liaisons radioélectriques existantes, aussi bien pendant la démonstration du prototype qu'en prévision de la mise en œuvre du système dans tout son parc de véhicules.

Le projet a comporté le développement d'un système de communications et de localisation de véhicules, et l'essai de celui-ci à bord de 10 des 73 autobus déjà dotés d'un matériel DAP, lequel comprend une antenne et un récepteur GPS, un émetteur-récepteur infrarouge et un ordinateur de bord pour la collecte de données. Cette approche a été adoptée sachant que d'autres appareils de ce type pourraient être fournis et installés à un coût tel que l'utilisation de l'AVL dans tout le parc allait être économiquement viable pour Winnipeg Transit.

Les travaux en marge du projet ont débuté en 2003 avec le développement d'un nouveau contrôleur radio embarqué, qui a remplacé le récepteur radio, le combiné et le microphone mains libres utilisés dans les situations d'urgence. Puis, une interface conducteur (IC) a été développée, avec écran d'affichage reconfigurable. Ces composants étaient reliés les uns aux autres et offraient une compatibilité amont, du fait qu'ils continuaient de permettre des radiocommunications avec le centre de commande. Les essais, qui se sont étalés sur plusieurs mois, ont démontré qu'ils étaient fiables et robustes et que l'IC était conviviale.

En même temps que la mise à niveau du matériel radio embarqué, une solution de rechange moderne aux unités de signalisation de base (BSU, *base signalling unit*) hébergées dans les émetteurs relais était aussi développée. Les BSU relaient les messages de données entre les autobus et le système de radiocommande informatisé du centre de commande. Le nouveau BSU était conçu pour appuyer à la fois les communications en phonie existantes avec les autobus dotés du nouveau matériel, et les nouveaux types de messages de données que nécessiterait le système de contrôle du respect de l'horaire, de même que d'autres fonctions évoluées envisagées, comme la messagerie texte.

Le développement du système embarqué de contrôle du respect de l'horaire a commencé par la création, par Infodev, d'une technique permettant de comprimer le fichier complet de l'horaire général d'une période d'affectation (une saison), pour pouvoir télécharger l'horaire de chaque parcours/circuit dans la mémoire disponible du microprocesseur d'enregistrement des données de chaque autobus. Cela donne toute la souplesse voulue pour déterminer ou modifier les affectations des autobus pendant la journée. Une méthode et une technologie pour le transfert aux autobus des données sur les horaires ont été développées, qui font appel à des modems à étalement du spectre de radiofréquences (RF). La technologie RF a été utilisée pour établir quotidiennement la valeur du parcours/circuit dans l'enregistreur de données de l'autobus, afin qu'il puisse décomprimer le bon horaire. L'enregistreur de données pouvait aussi recevoir cette

instruction par la radio de l'autobus. L'autobus pouvait ainsi être réaffecté au cours de la journée, auquel cas la valeur «circuit» était modifiée en conséquence.

Chaque parcours/circuit est jalonné de plusieurs endroits désignés «points de chronométrage», aux fins de l'établissement des horaires. Ces points sont normalement situés aux extrémités du parcours, et aux arrêts importants en cours de route. Le temps de parcours entre les points de chronométrage est de 10 à 15 minutes, en moyenne, et il existe un certain nombre d'arrêts intermédiaires entre ces points. La base de données des horaires contient les coordonnées (latitude et longitude) de chaque point de chronométrage. Le «moteur» de contrôle du respect de l'horaire développé par Infodev utilise les données d'entrée GPS et un algorithme complexe pour déterminer l'écart *réel* par rapport à l'horaire aux points de chronométrage et l'écart *prévu*, entre les points de chronométrage.

L'IC sert à afficher en continu l'information sur le respect de l'horaire pour le bénéfice des chauffeurs d'autobus. L'écart par rapport à l'horaire est exprimé en minutes et en secondes, affectées du signe positif si l'autobus est en avance, ou du signe négatif, s'il est en retard. Le but est de se rapprocher le plus possible d'un écart zéro par rapport à l'horaire.

L'autobus transmet par radio au centre de commande les rapports d'écarts par rapport à l'horaire. Ces rapports sont produits automatiquement par le système lorsque les paramètres établis sont dépassés. Aux fins de l'essai, le système était configuré pour envoyer des rapports d'écarts si un autobus était en retard de plus de cinq minutes ou en avance de plus de deux minutes, conformément aux protocoles d'exploitation de Winnipeg Transit et aux critères imposés aux chauffeurs pour la production de rapports. Des rapports d'écarts peuvent aussi être produits si l'autobus n'atteint pas un point de chronométrage à l'intérieur d'un certain intervalle par rapport à l'heure ou la distance prévue, ce qui indique que l'autobus pourrait avoir dévié de sa route ou pourrait éprouver d'autres difficultés.

Le projet comportait en outre l'amélioration du système de commande des communications et de gestion des incidents du centre de commande, afin qu'il puisse gérer la production de rapports sur le respect de l'horaire en temps réel. Il a été jugé préférable de remplacer le système CONTACT existant, plutôt que d'y apporter les modifications majeures qui s'imposaient. Winnipeg Transit a donc entrepris le développement du nouveau système Intracom. Intracom offrira un outil de communication et de gestion des incidents plus fiable et plus robuste pour les contrôleurs. Intracom servira de point central pour le traitement et l'interprétation des données en temps réel sur le respect de l'horaire et pour la transmission de ces données à d'autres services de renseignements aux voyageurs. Intracom a aussi été conçu pour offrir les fonctions évoluées suivantes :

- messagerie texte bidirectionnelle avec les autobus, afin de diminuer le recours aux communications en phonie et d'améliorer la diffusion, la conservation et la récupération des données

- notifications automatisées de passagers en correspondance permettant aux chauffeurs d'autobus d'avertir les autres autobus que des passagers en correspondance arrivent
- enregistrement autonome de données sur des faits courants, à des fins statistiques, p. ex., utilisation du support à vélos
- fonction intelligente de «visualisation du service» et de «modélisation du service» pour le bénéfice des surveillants; analyse des perturbations de service à grande échelle et recommandation des modifications à apporter pour ramener le service à la normale

L'essai du système embarqué de contrôle du respect de l'horaire a démontré la capacité de celui-ci de déterminer avec une grande précision la situation des autobus par rapport à leur horaire, de présenter en continu cette information aux chauffeurs et de produire automatiquement des rapports d'écarts et les transmettre par radio au nouveau système Intracom. Mettre en œuvre un système de cette nature réduira le trafic de données nécessaire pour obtenir l'information en temps réel sur le respect de l'horaire dans tout le parc, rendant possible l'utilisation des bandes/radiofréquences actuelles, sans frais supplémentaires. Le matériel embarqué nécessaire peut être compact et durable et peut être acheté à bon coût. L'information embarquée supplémentaire ainsi acquise peut aussi être utilisée pour soutenir d'autres périphériques, comme des dispositifs d'annonce du prochain arrêt, ou l'activation des signaux de priorité uniquement pour les autobus qui sont en retard. Les grands réseaux de transport en commun peuvent particulièrement tirer avantage de cette approche pour la localisation des véhicules et le contrôle du respect de l'horaire en temps réel.

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Table 1 Regular and Charter/Special Event Service Statistics 1

GLOSSARY

APC	Automatic Passenger Counting
AVL	Automated Vehicle Location
Booking	A transit schedule for a seasonal time period
BSU	Base Signalling Unit
CONTACT	Winnipeg Transit bus communication and incident management system
DIU	Driver Interface Unit
DSP	Digital Signal Processor
GPS	Global Positioning System
HASTUS	Trade name for transit scheduling software
Intracom	Integrated Transit Communication system
IR	Infrared
IVR	Interactive Voice Response
MMIS	Maintenance Management Information System
Navigo	Winnipeg Transit internet trip planning tool
NETData	Winnipeg Transit networked transit service database
ONTRAC	Online Transit Resource Allocation and Control system
RF	Radio Frequency
Route	A designated bus routing, with applicable schedules
RRS	Radio Relay Server
Run	A schedule for an individual bus operating on any given route(s)
SA	Schedule Adherence

Telebus	Winnipeg Transit telephone schedules information system
TP	Timing Point
Trip	A series of Timing Points with a start and finish on a Run
UHF	Ultra High Frequency (radio)

1. INTRODUCTION

1.1 General

This report describes the development, implementation and testing of an advanced transit communications and location system, based on the concept of an urban transit "smart bus" with on-board schedule adherence intelligence. This research and development project was undertaken in partnership between The City of Winnipeg Transit System and Infodev Electronic Designers Limited over a three year period. The development of a reliable, intelligent and cost-effective system for providing real-time transit schedule adherence data that can be used for operational and customer information applications will assist both large and small transit systems considering the implementation of such technology.

1.2 Winnipeg Transit System Overview

Winnipeg Transit is a municipal transit system operated by the City of Winnipeg, located in Manitoba, Canada. Winnipeg Transit is responsible for the delivery of public transportation services in Winnipeg, serving an area of 116,000 acres with a population of approximately 650,000. Public transportation services include: (i) fixed route and demand responsive regular transit services (ii) paratransit service for persons with disabilities and (iii) chartered and special event services. The department has a staff complement of 1278 full time equivalent employees and a total operating budget of $108M. *Table 1 provides key service statistics for regular and chartered/special event transit services.*

Table 1 Regular and Charter/Special Event Service Statistics (2004)

Buses	535
Bus hours operated	1,359,733
Bus kilometres operated	26,446,530
Revenue Passengers	38,618,376
Average Weekday Passengers	135,000
Number of Routes	86
Bus Stops	4,800
Transit passenger shelters	880

1.3 Existing Systems Supporting Operations and Customer Information

The delivery of transit services is heavily dependent on a series of information systems. Winnipeg Transit's strategy has been to assure seamless integration of information flow from end-to-end throughout the required business processes. In order to enable this high degree of integration, Winnipeg Transit has undertaken to custom design and develop the majority of its pillar information systems in-house.

Currently deployed systems cover the entire range of functions from initial service design, through service implementation and service control to customer information delivery. The cornerstone of the information management strategy has been the centralization of all service information in a single operational data repository named "NETData". All originating data systems store service information in NETData. Any process requiring service information draws data from NETData. NETData today is designed to support the management of real-time service exception data.

Figure 1 depicts the data integration model for Winnipeg Transit.

For a more complete description of information systems deployed by Winnipeg Transit see Section 3.

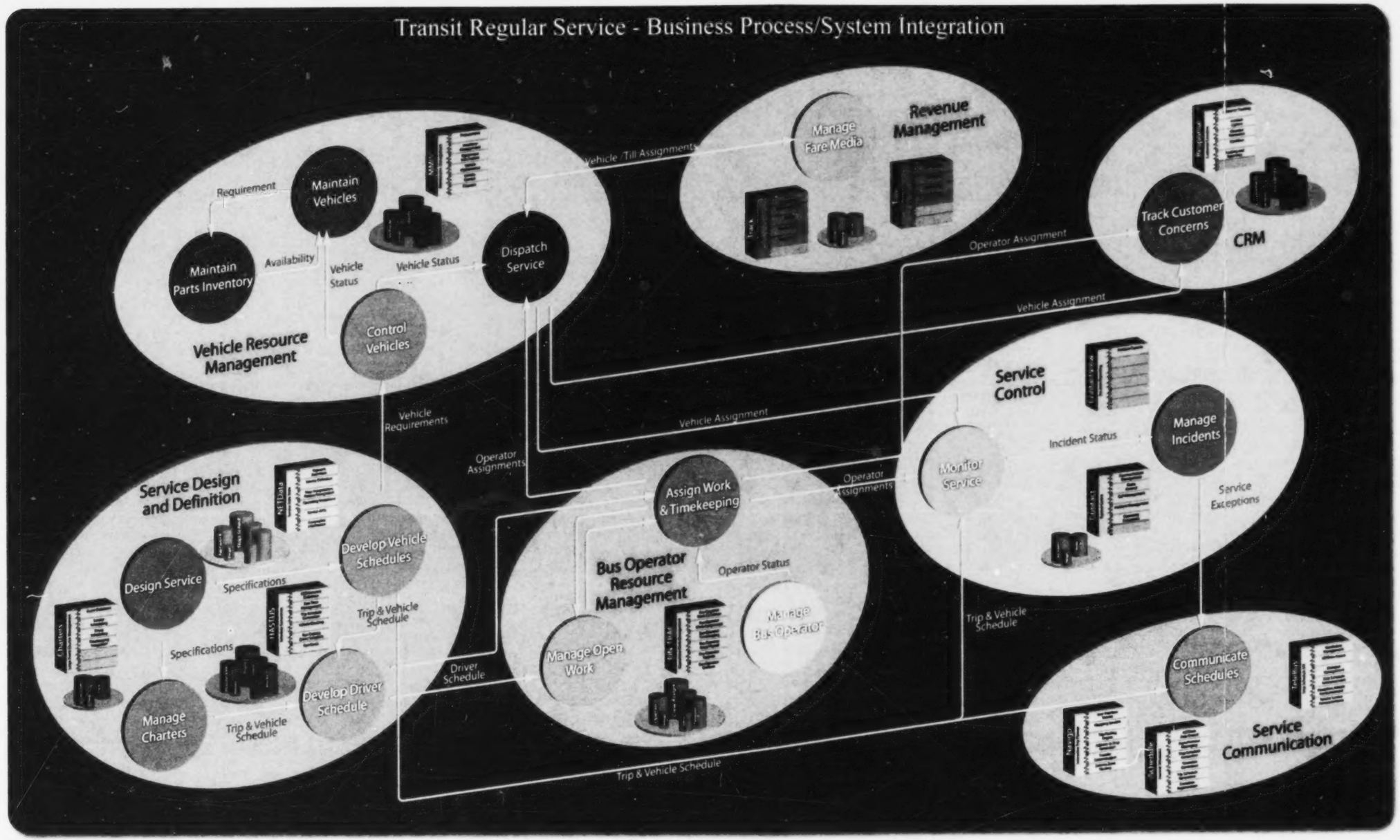


Figure 1 Data Integration Model for Winnipeg Transit

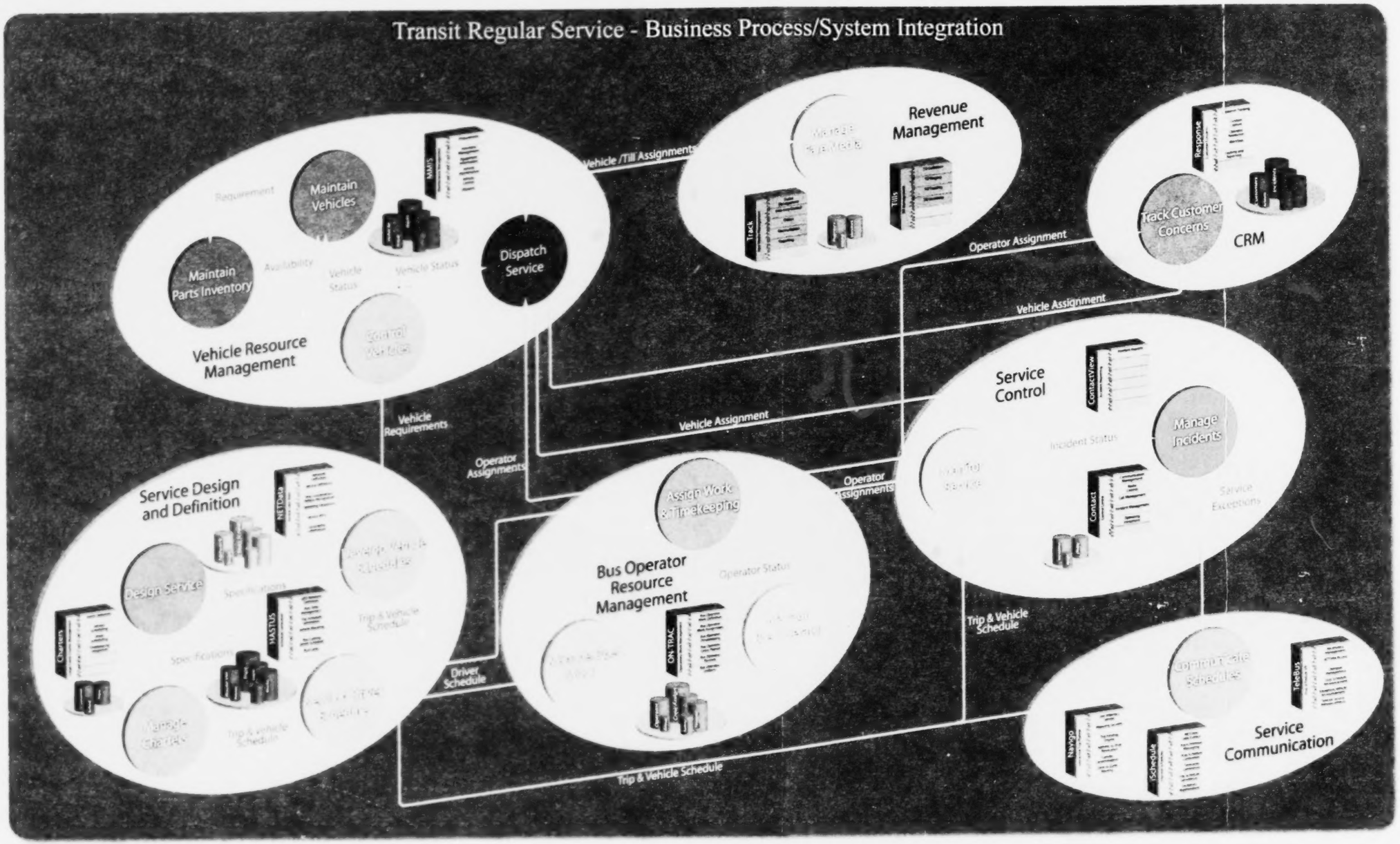


Figure 1 Data Integration Model for Winnipeg Transit

1.4 Future ITS Based Services

Intelligent Transportation Systems rely on the integrated use of technology to coordinate priority and traffic flow to enhance traffic operations. Technology can also be used to provide automated traveler information. The building block for many of these transit applications is an AVL system, such that the location of each bus is automatically known in direct relation to its schedule. Without this, transit systems have historically relied on bus operators notifying supervisory staff via radio, or other means, that they are delayed or forced to detour. Operating ahead of schedule or deliberately not following the planned route often goes unreported.

Figure 2 depicts the visualized application of AVL technology to future transit operational and ITS applications.

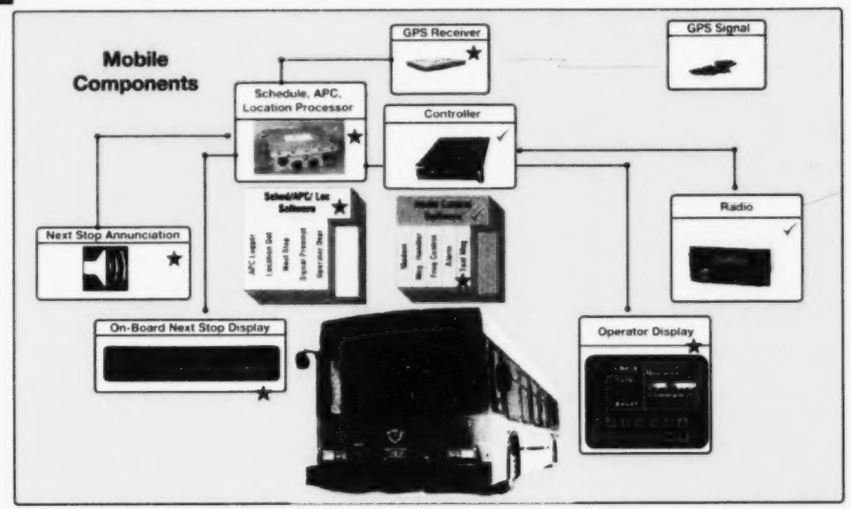
Within this project, Winnipeg Transit identified three main immediate uses of real-time schedule adherence information, as will be described in detail later in this report:

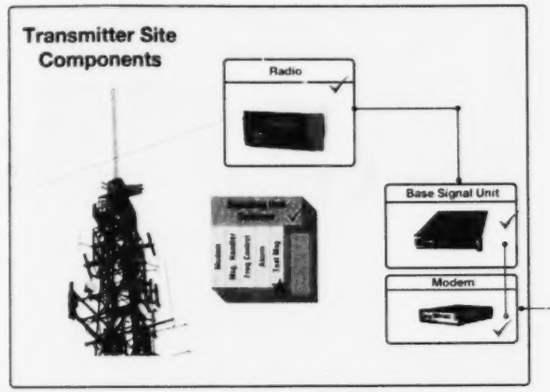
- Automatic updating of current schedules information available through its information systems, for customers and Transit Customer Service Representatives
- Displaying to the bus operator their actual schedule performance, in order to potentially influence their performance and improve their schedule observation.
- Assisting supervisory staff regulating transit service and responding to disruptions with automated schedule adherence information for each bus, for an entire route, or for the system as a whole.

There are a number of future ITS applications that Winnipeg Transit is considering in conjunction with the implementation of an advanced communications and location system. These include:

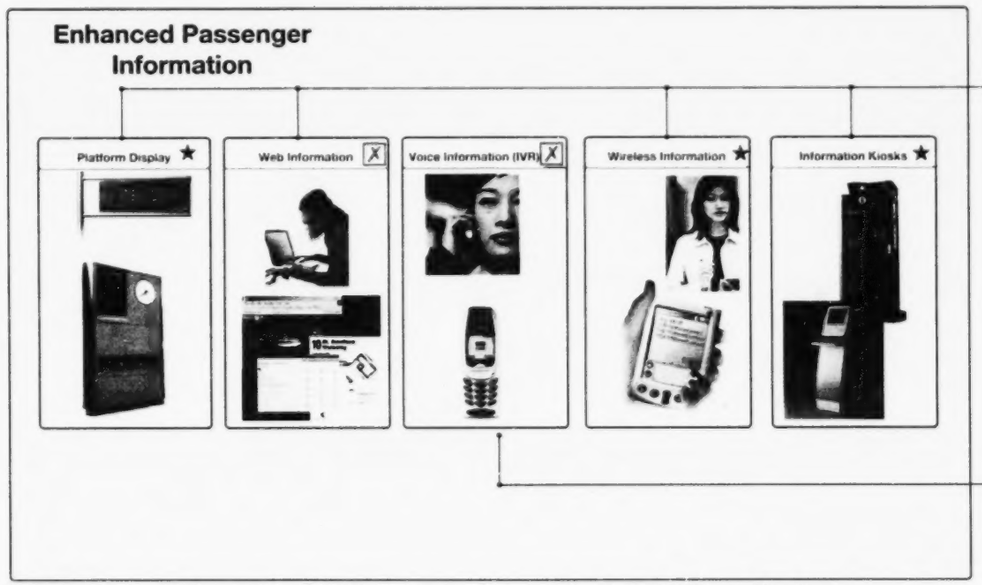
- Traffic Signal Priority (TSP) measures to improve performance of existing transit-only reserved traffic lanes and for future Bus Rapid Transit (BRT) using "busways" or "bus corridors" (roads built for the exclusive use of buses). An approaching bus will cause a traffic signal controller to trigger such things as: prolonged green phase, truncated opposing red phase, or bus only priority phase. This can apply to all buses, or only those buses behind schedule.
- Real-time next bus displays at terminals, busy bus stops and major activity centers.
- On-board next stop announcements using visual displays and voice messages.

Bus Radio - Vehicle Location - Passenger Information Schematic





✓ = Existing Component to be Replaced
★ = New Component or Software Function
X = Exiting Software Function to be Enhanced with Real-Time Schedule Information



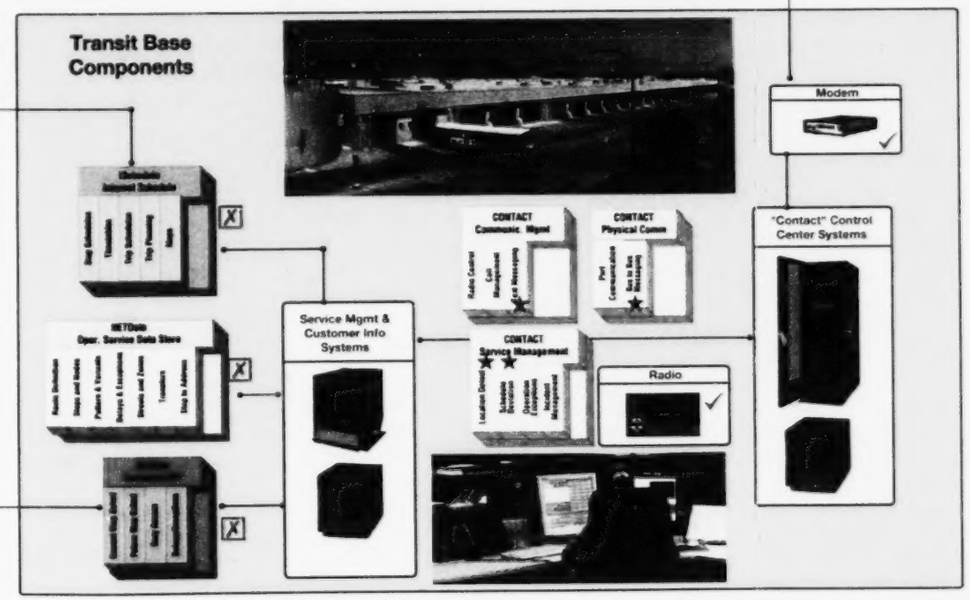
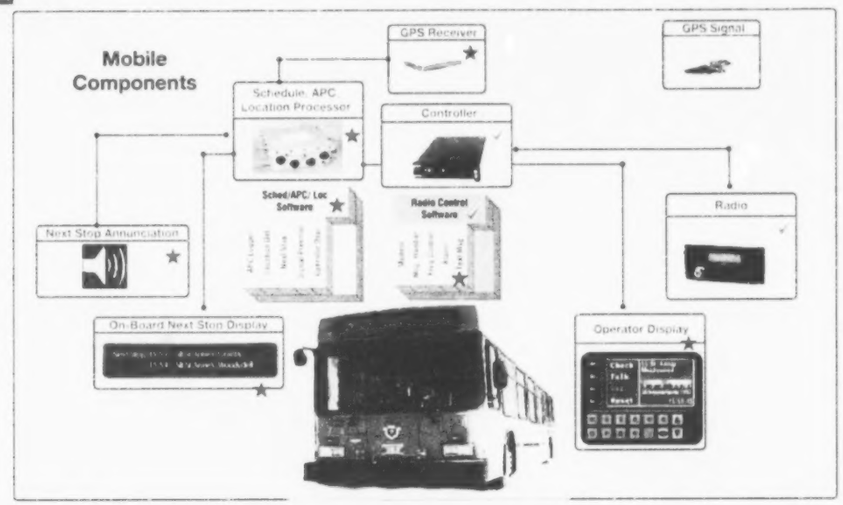
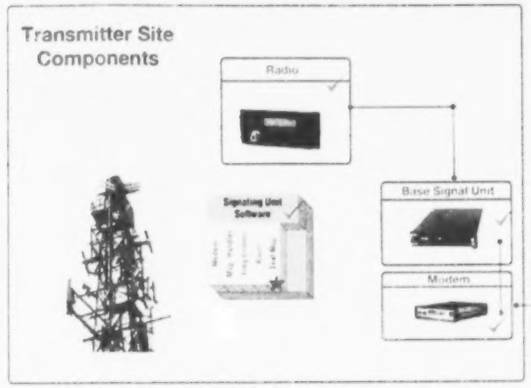


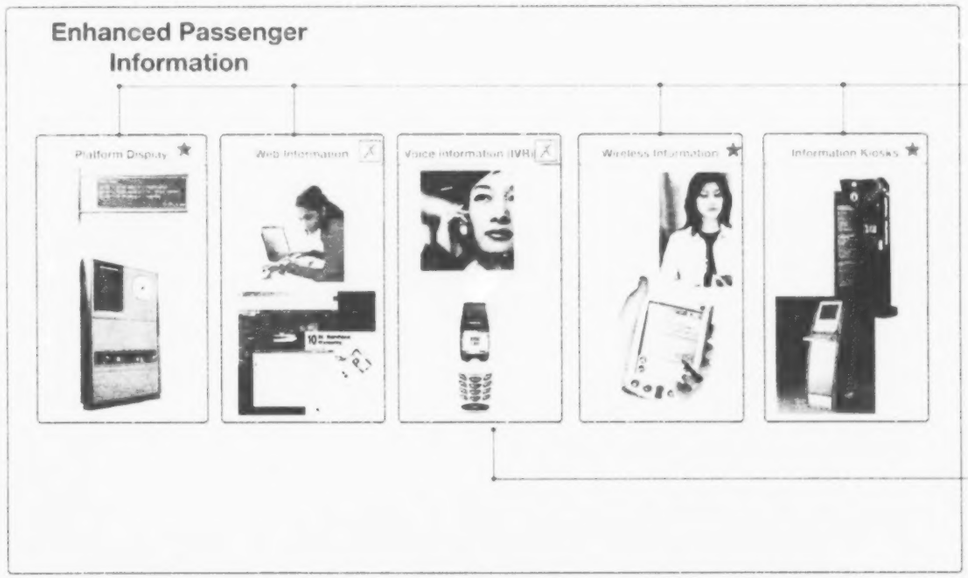
Figure 2 Future uses of AVL for transit operational and ITS applications

Winnipeg Transit Department

Bus Radio - Vehicle Location - Passenger Information Schematic







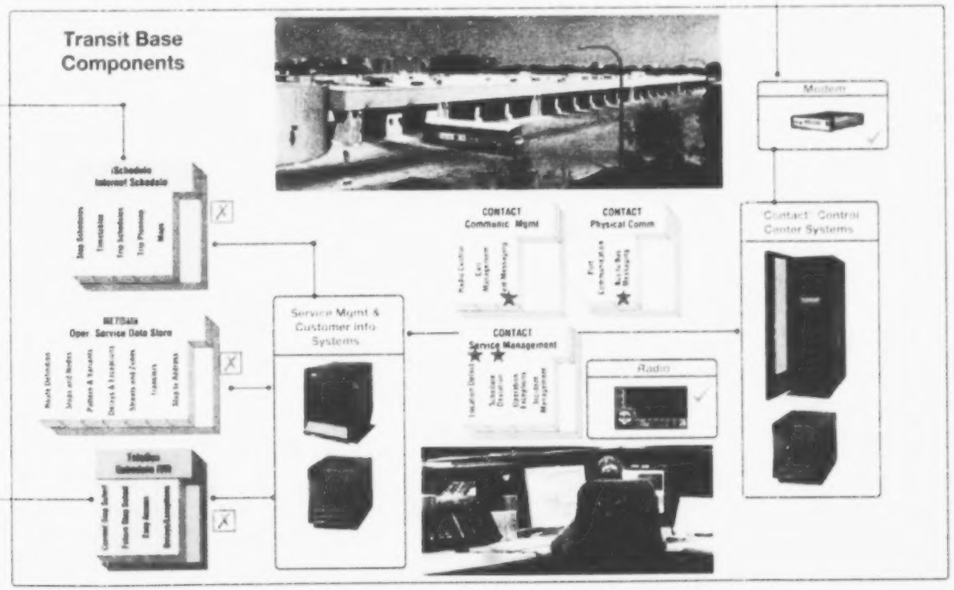


Figure 2 Future uses of AVL for transit operational and ITS applications

- Interactive schedules information available through portable, handheld devices such as cell phones and PDAs.

- Dynamic, automated adjustment of service levels and vehicle schedules for recovery from mass service disruptions.

1.5 Partnership With Infodev Electronic Designers Limited

This project took place through a unique public-private partnership between Winnipeg Transit, a department of the City of Winnipeg, and Infodev Electronic Designers Limited (Infodev) a privately held company based in Quebec City, Quebec, Canada.

Infodev has been a leading supplier of automated people counting systems for shopping malls, airports, museums and casinos for many years. More recently, they have developed expertise in automated passenger counting (APC) systems for buses, light rail, trains and subways. Infodev supplied Winnipeg Transit with an APC system for 73 of its buses in 2002.

Through the Winnipeg APC project and others, Infodev has gained considerable experience using GPS for transit applications. They have developed sophisticated on-board data logging techniques/equipment and schedule adherence algorithms for capturing and analyzing passenger traffic data. This system records the number of passengers boarding and/or alighting at every individual bus stop, and also measures running times and schedule adherence for later analysis.

Infodev also has experience in electronics, data transfer and radio related technologies, such as digital signal processing and spread spectrum RF (radio frequency).

Winnipeg Transit, through its Information Systems Division, has custom developed and supports most of its pillar operating systems internally and has extensive experience with system integration. These systems are described in Section 1.3, but include NETData, CONTACT, ONTRAC, MMIS and web applications. Winnipeg Transit therefore has substantial expertise with the existing bus radio control system and incident management applications, together with the structuring, transfer and sharing of data between this and all other systems. Winnipeg Transit also invested significantly in database development to support the APC project. This database contains all of the key schedules and geographic information needed to support other AVL uses, including the current Project. There was, therefore, an opportunity to leverage this information.

The City of Winnipeg, through its corporate Communications Systems Branch, also has broad experience in radio technology, both voice and data. This group maintains all City radio infrastructure in vehicles and buildings for Police, Fire/Paramedics, public works, Winnipeg Transit and others.

Discussions began in 2001 between Winnipeg Transit and Infodev about the planned replacement of the aging bus radio system and the desire to implement advanced functions based on real-time schedule adherence. Infodev expressed interest in working with Winnipeg Transit to develop an AVL system with features specific and essential to the transit industry, which has needs different than those in emergency services or other public services. They had confidence in their abilities to design and construct software and hardware that could later be offered to the international transit market at a cost more competitive than other existing companies in this field. Of great importance to Winnipeg Transit was the preference to seamlessly integrate new radio technology and new functionality, while continuing to support the existing radio system until conversion could be completed. Infodev was committed to developing a new system around this approach.

A project team was assembled, with expertise drawn from the Infodev research and development group, from the Winnipeg Transit IT team, from Transit Operations and from the Communications Systems Branch. Preliminary work began in 2002, using the existing financial resources of Winnipeg Transit and Infodev. In 2003 Transport Canada provided additional funding support for a full prototype development project.

2. PROJECT OBJECTIVES

2.1 Transport Canada Project Objectives

The primary objective of the Project was to develop an urban transit "smart bus" platform, one capable of autonomously determining real-time schedule adherence, in order to be the foundation for a wide range of ITS applications supporting transit operations, planning and customer service functions. The approach was to develop and test a transit communications system that includes an AVL capability and that performs schedule adherence calculations locally on-board each vehicle and transmits information to a central computer for only the buses that are not operating within a designated tolerance of the planned schedule.

Most modern systems today rely on the use of the Global Positioning System (GPS) to obtain accurate vehicle locations. This technology was already being used on 73 Winnipeg Transit buses for automated passenger counting and had proven to be accurate and reliable.

For some transit applications it is enough to simply know the physical location of buses and whether they are moving or stopped. For instance, the emergency response to an incident involving a transit vehicle can be reduced by knowing the actual location of a bus versus its scheduled location, which can vary depending if the bus is early, late or off route. Many existing GPS-based AVL systems simply show the physical position of vehicles through a text description or a map display.

However, for most transit applications it is necessary to also know the schedule performance of the bus in real-time. A schedule adherence determination must be made by comparing the actual location of a bus to its scheduled location, using time, speed and heading.

The general approach that has been used by AVL systems is for a central computer to continually poll the locations of all transit vehicles, via radio, cell network or other means, to retrieve location/speed/heading data for subsequent centralized data processing. The central computer houses a master schedule for all routes/runs and constantly does the schedule adherence comparison for all buses in service and may in turn report the results back to the buses themselves. This approach requires a large volume of data to be constantly transmitted, requiring considerable radio bandwidth and channel capacity or in the case of common carrier shared cellular data technology technology, airtime. For small transit systems with few buses (e.g. less than 50) this may be less of a problem or cost factor, but for larger systems with 500-2000 buses, this can represent a very significant technical issue and capital or operating investment in terms of acquiring the necessary radio or wireless capacity and infrastructure. For instance, the costs for cellular network airtime are in the range of $50-70 per month, per vehicle. For a system the size of Winnipeg Transit, this would represent an annual airtime rental cost of approximately $400,000.

The alternative method is to perform the schedule adherence calculation on a local computer on-board each bus. The "Smart Bus" only needs to report to a central computer when there is a schedule deviation exceeding set parameters, otherwise the bus is assumed to be operating on its planned route and schedule. The Bus operator has continuous feedback regarding his schedule performance, autonomously. As most Winnipeg Transit vehicles operate within planned tolerances (*as shown in Figure 3*), this approach can greatly reduce the volume of data to be sent from (and to) buses and the central control center, minimizing costs for the communication network. However, there is some potential additional cost from needing to install additional computing capacity on-board each bus, if this is not already available. This project relied on the use of the existing Infodev APC data logging microprocessor on 73 buses, at no additional hardware cost. The project approach was premised on the knowledge that additional units of this type can be supplied and installed at a cost that makes fleet-wide use for AVL economically practical (approximately $2,500 per unit).

To support the AVL system and other planned new functions, such as text messaging, it was necessary to also replace the aging radio equipment and driver interface units on-board buses, together with radio equipment at base signaling tower sites as part of the Transport Canada project. This objective here was to continue to use existing radio frequencies and develop a new system that could seamlessly support both existing bus radios/functionality and new generation equipment and features as they would be phased in over 2-3 years.

The final Transport Canada project component was the need to update the Winnipeg Transit Control Center CONTACT system, in order to also support AVL and other proposed new functions.

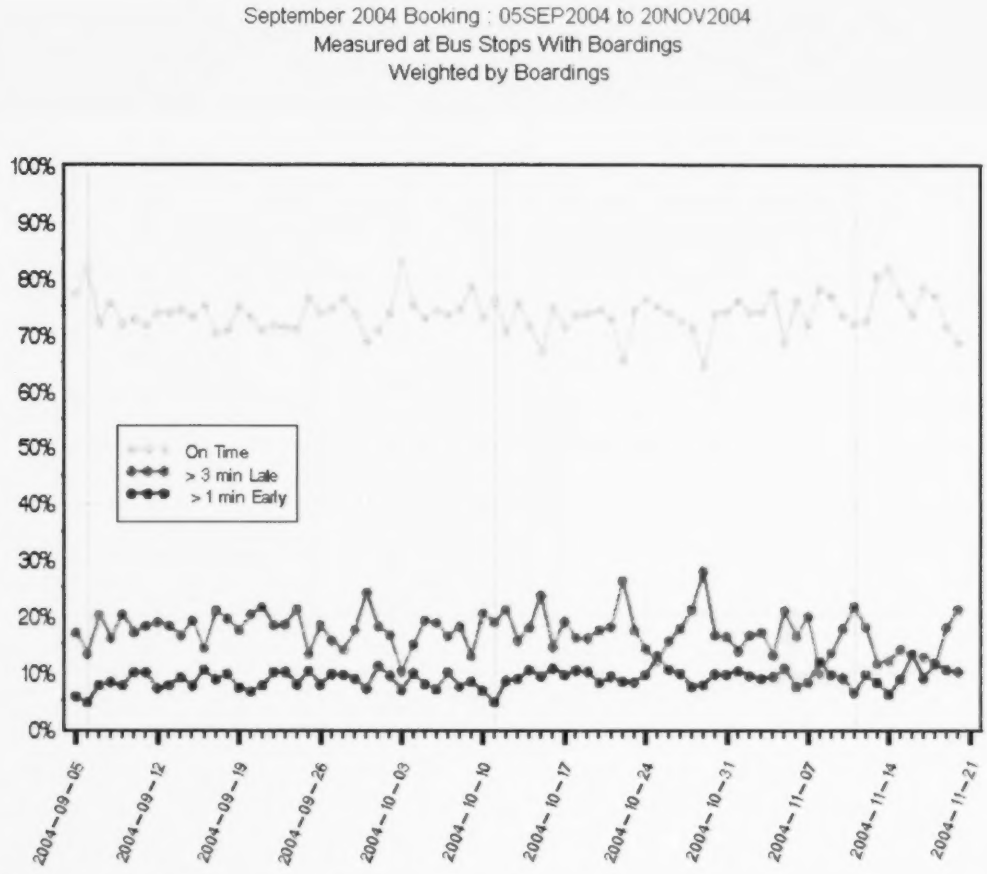


Figure 3 System-Wide Schedule Adherence

2.2 Overall Winnipeg Transit Project Objectives

The objectives for the overall project undertaken by Winnipeg Transit are broader and go beyond replacement of the existing radio equipment and the implementation of an AVL system capable of calculating schedule adherence on-board each bus. Several new advanced functions were identified as desirable for the new communication system and as well, a decision was made to replace, rather than upgrade, the existing Control Center CONTACT system.

For the purposes of improved service control and service quality, several additional communication features were added as project objectives:

- Two-way text messaging between central control and buses
- Bus-to-bus communication/notification
- Field supervisor-to-bus communication

- Enhanced DIU capabilities
  - schedule adherence display
  - timing point or stop level schedule display
  - additional communication request prioritization
  - text message notification, storage and retrieval
  - operator log in
  - flexible configuration

The decision to replace CONTACT and develop a completely new system for the Transit Control Center for managing communications and incident processing was based on several known weaknesses inherent to the existing system:

(i) Limitations of the aging development tools upon which CONTACT was built, affecting the speed and stability of the system and ease with which changes could be made

(ii) Anticipated obsolescence of these development tools and discontinuance of supplier support

(iii) System architectural design deficiencies within CONTACT creating a dependence on internal network connections being available, even for basic communication functions to work

However, another reason for starting fresh was a vision for creating a system which could automate many service control functions and decisions which historically have been performed by trained supervisory staff. Routine recording of certain events for statistical purposes, could, for example, be performed without human intervention. But of more significance was the concept of doing "service modeling" or "service visualization" in order to assist with major service disruptions. In storm situations, for instance, supervisory personnel can become overwhelmed with delayed bus reports and service can be very unevenly spaced. A system that can analyse all of the delay reports and quickly develop a service recovery plan could be of great benefit to resuming normal operations.

3. EXISTING SYSTEM DESCRIPTION

3.1 Existing Information Systems Supporting Operations and Customer Service

3.1.1 Data Management

Winnipeg Transit employs a data warehouse approach to database management, wherein all common transit service data is stored in one central location and shared between the department's individual information systems, to eliminate duplication, parallel maintenance and inaccuracies. NETData is the central repository for all operational data related to: route timetables, bus stop locations, stop schedules, bus operator assignments, vehicle assignments, and service exceptions. As such, it is interfaced with several other Transit operating and customer information systems to transfer information to or from the data store.

3.1.2 Service Design and Definition

For transit scheduling, Winnipeg Transit utilizes the HASTUS scheduling tool purchased from Giro Inc. This system produces transit master route schedules and bus operator "crew" (or work) assignments. Schedule data is exported to NETData. Crew assignment data is exported to another system known as ONTRAC, which is the transit Bus operator resource allocation and payroll management system.

3.1.3 Bus Operator Resource Management

ONTRAC (Online Transit Resource Allocation and Control) is used to manage the daily work assignments for the 1000 Bus operators employed to deliver transit services. This system was developed in-house in 1982 and operates on a IBM AS 400 platform. The system creates a daily and biweekly gross payroll and captures all absence exceptions. The twice daily assignment of buses to each individual "run" (or vehicle schedule) is also a function of the ONTRAC tool. Finally, ONTRAC is also used by senior supervisory staff to track and manage overall employee performance in all areas, including safety, attendance, customer service and training.

3.1.4 Vehicle Resource Management

MMIS (Maintenance Management Information System) is used to support fleet maintenance activities, central stores, dispatching buses to routes and vehicle parking in the garages. Developed internally in 1996, this system operates through the AS 400 platform. The bus dispatch assignments are exported to NETData.

3.1.5 Service Management and Control

CONTACT is the existing transit Control Centre system for sustaining fleet radio communications and for incident management functions, including service exceptions

such as delays, detours and route/run cancellations. A client/server based system, it was developed internally and implemented in 1999. It utilizes a combination of PC based and AS 400 applications. CONTACT interfaces with NETData for schedules information and bus dispatch assignments, and with ONTRAC for operator work assignments. CONTACT also passes service exception information to NETData. CONTACT is explained in more detail later in this section.

3.1.6 Customer Information

Telebus is a 24-hour automated schedules information system which allows customers to access current or future transit bus times via telephone. Callers receive times for the next three buses on all routes serving a particular stop. Telebus is updated with service disruption information, and with low floor accessible bus assignments from NETData.

Winnipeg Transit's website www.winnipegtransit.com provides visitors access to transit route maps, route schedules and stop level timetables, both current and future. An application known as iSchedule supports these functions. Schedules information is updated with service exceptions, and with low floor accessible bus assignments from NETData.

Another online feature is the popular interactive transit trip planning tool *Navigo.* This system was developed by Transit IT staff in 2002. Navigo allows users to enter an origin and destination for their planned trip, using four options: (i) address (ii) intersection (iii) landmark or (iv) bus stop number. The customer is then prompted for a departure or arrival time, and can specify requirements for transfer times, walking times and any need for wheelchair accessible service. The system will search for available trip options and present those to the user. This information will include all route numbers, bus stop locations, walking times and transfer directions. An optional graphical map display is available and all information can be printed. *Figure 4 shows a typical presentation of trip options and trip map generated by Navigo.*

RESPONSE is the management system used to record, investigate and respond to public and customer concerns and commendations. Workflow processes are automated and multiple users can simultaneously access the system. There are integrated functions for bus operator determination.

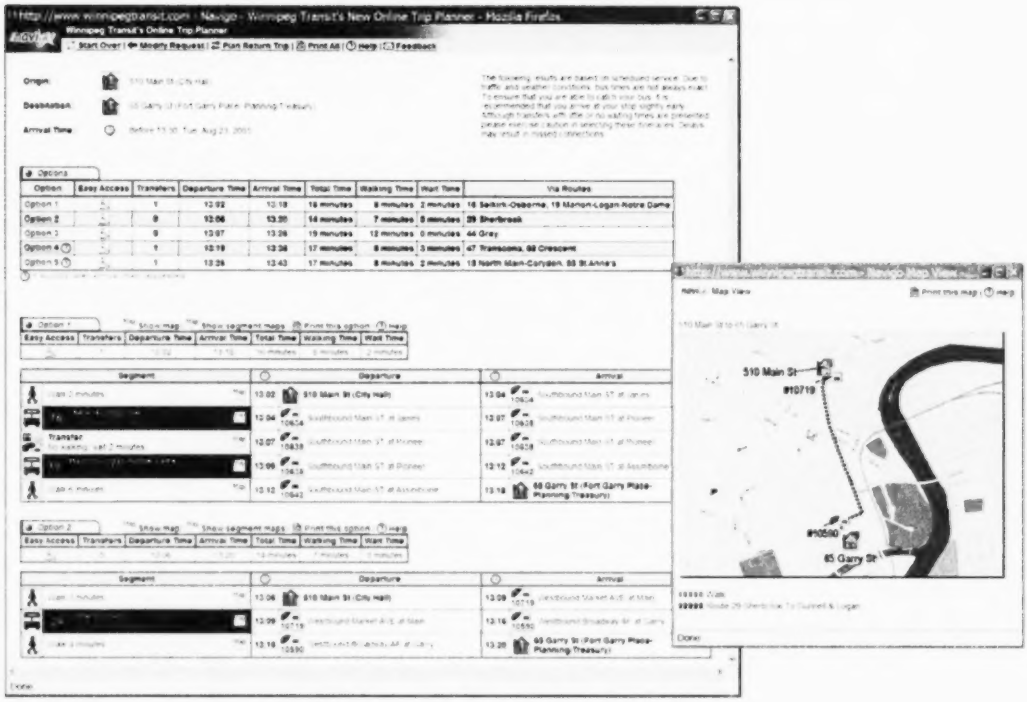


Figure 4 Example of *Navigo* trip options and trip map

3.2 Existing Bus Radio System Overview

The Winnipeg Transit existing bus radio communication system was initially implemented in 1982. The system utilizes one data channel and four voice channels operating on UHF (ultra high frequencies). Known as a "semi-trunked" system, it allows Control Centre supervisory staff to communicate privately with Bus operators individually, or make calls to groups of buses or all buses. It also allows Bus operators to place calls of different priorities to the Control Centre.

Management of radio communication functions, incident response and management reporting is computerized, as discussed in Section 3.4.

3.2.1 Existing On-board Bus Radio Components

Each bus is equipped with an eight channel General Electric MASTR EXEC II mobile radio equipped for five channels, a Ferritronics VEU-8-WT signalling and control board, a four button driver interface unit (DIU), a handset, speaker, silent alarm switch, goose neck public address (PA) microphone and antenna. *Figures 5, 6 and 7 depict the existing on-board radio components.*

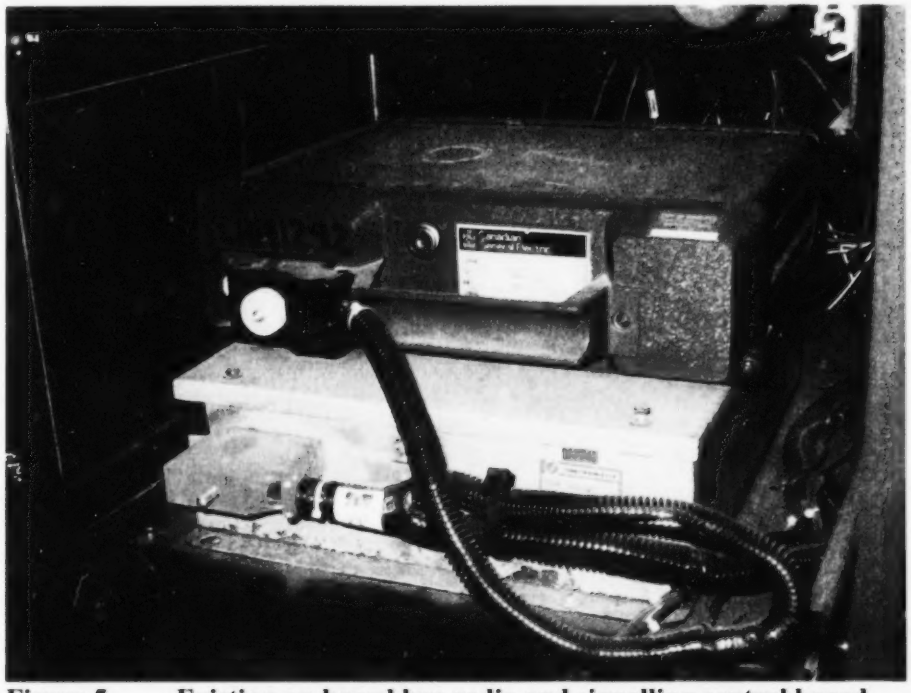


Figure 5 Existing on-board bus radio and signalling control board

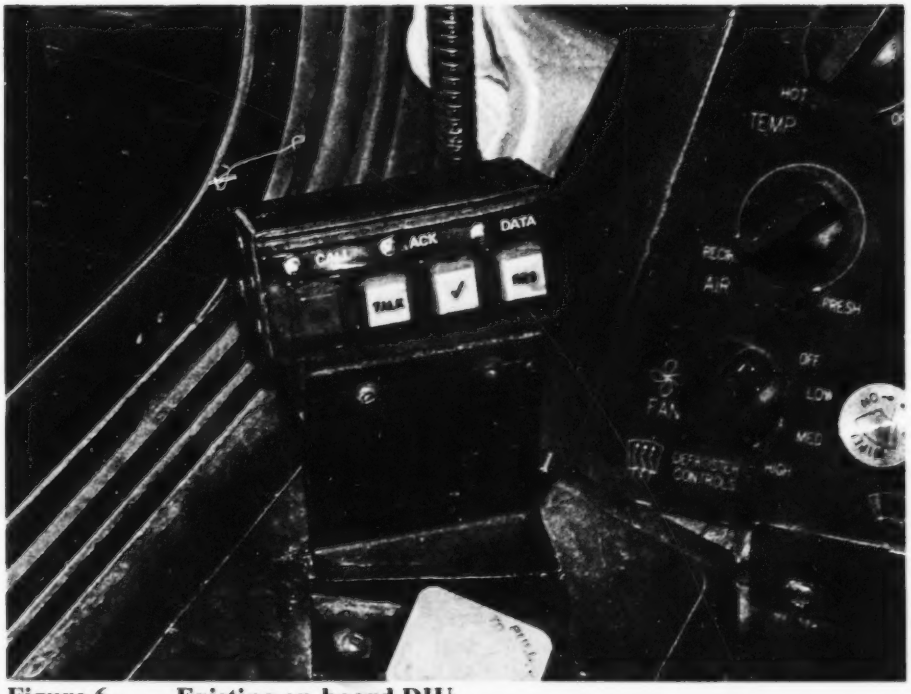


Figure 6 Existing on-board DIU

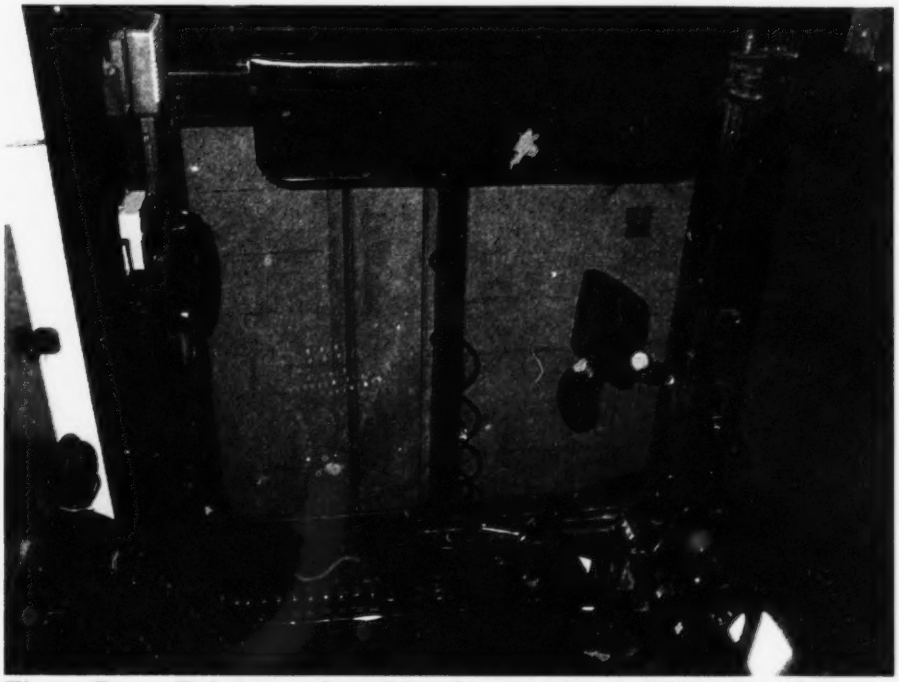


Figure 7 Existing on-board handset, speaker and PA microphone

3.2.2 Existing Call Types

The Control Centre can place three different types of calls to buses:

- Private Call to one bus
  – two-way communication between Controller and Bus operator
- Group Call to several buses, which may be selected by route or bus stop(s) served
  – one way communication i.e. an announcement by Control
- All Call to all buses in-service (including those not currently assigned to a run)
  – one way communication i.e. announcement by Control

Bus operators can place calls to the Control Centre using four different priorities dependant on the circumstance:

- Silent Alarm
- 911
- Talk
- ✓ (Check)

3.2.3 Existing Base Signalling Equipment

Fixed radio equipment and Base Signalling/Control Units (BSUs) (or BCUs) are located at two separate sites in downtown Winnipeg on the roof of commercial buildings. The base stations operate on a duplex basis with automatic repeater operation provided on the four voice channels. They are connected to the Transit Control Centre via telephone lines. The BSU's interface to the radio base stations and via modems to the Control Centre CONTACT system. *Figure 8 shows one of the base signalling site locations.*

At any given time one BSU will be designated as the Master and the other as a Slave. Each site supports the data channel and two voice channels. Excellent city-wide radio coverage is attained from either site. It should be noted Winnipeg is located on the Canadian prairies, where the topography is very flat. *Figure 9 shows an existing Ferritronics BCU.*

Figure 8 Base signalling site at 55 Nassau Street

Figure 9 Existing BCU (top) and modem (bottom)

3.3 Existing Administrative Radio System

On-street supervisory vehicles for Inspectors, as well as all other maintenance and support vehicles, are equipped with Motorola two-way VHF (Very High Frequency) mobile radios. Inspectors also carry Motorola portable radios. A radio repeater is located on top of a downtown commercial building. Base stations are located in the Transit Control Center and in several other remote locations.

All communication takes place on a single open channel. This allows for sharing of all transmitted information, but does not provide any privacy for sensitive matters. Consequently, Inspectors also utilize cellular telephones.

Given this is a separate system from the Bus Radio system, direct communication between Inspectors and bus operators is not possible. Messages must be relayed through Controllers in the Control Center.

3.4 Existing CONTACT System

Winnipeg Transit first introduced a computerized bus radio communication system in 1982. The CARC system (Computer Assisted Radio Communication) provided the ability to manage and prioritize radio communications. It resided on a dedicated, non-networked microprocessor. While very fast and reliable, CARC offered limited functionality.

The CARC system has since been replaced by the CONTACT system, which was developed internally and implemented in 1999. CONTACT is the transit Control Center system for not only sustaining fleet radio communications, but also for supporting all incident response and management functions. CONTACT interfaces with a variety of other Winnipeg Transit operating systems to access or share information concerning schedules, bus assignments, Operator work assignments and service delays/cancellations.

CONTACT is a client-server application developed with VisualAge/SmallTalk object-oriented tools and using a windows based, graphical user interface. There are five client workstations, a communications server and a network server located in the Transit Control Centre. These systems operate in a Windows NT/2000 environment. In addition, a port server function (for communication to/from the BSU's) is performed on an IBM AS 400 platform.

Some of the main features of CONTACT are:

- Automated sharing of transit service data with other operating systems
- Simultaneous updating between server and client consoles
- Automated notification of receipt and prioritizing of incoming calls from buses
- Ability to place outgoing calls by bus number, bus run assignment or Operator assignment
- Ability to call groups of buses by route(s) or bus stop(s) serviced
- Incident notebook functions to record incident details and response
- Open Incident List functions to manage current incidents requiring response
- Event Logging of all incoming and outgoing data communications between the BSUs and CONTACT
- Management reporting and query functions

Figure 10 shows the user interface displays of the CONTACT system.

While the CONTACT system is a fairly robust system, offering many advanced features, it does suffer from an inherent weakness. The system is dependant on being able to receive information from other systems to which it is interfaced. When this is disrupted for any reason, e.g. due to a network outage, the system fails. This means even basic communication functions to/from buses is not possible. The original CARC system, which was retained as a backup, must be switched over to in these circumstances.

The CONTACT system, as it exists, is not capable of receiving new message types required by an advanced communication and AVL system, such as GPS schedule deviation reports, or is it capable of sending new types of data, such as text messages.

Figure 10 User interface of the Control Centre CONTACT system

3.5 Existing Use of Automated Vehicle Location Technology

Winnipeg Transit awarded a contract in the fall of 1999 to Infodev Electronic Designers for the supply and installation of Automatic Passenger Counting (APC) equipment on 60 buses.

The on-board components of the system include a global positioning system (GPS) antenna and receiver to determine the geographic location of buses, infrared sensors installed at the front and rear doors to count boardings and alightings at each stop, an infrared transceiver to automatically offload data when the bus returns to the garage at the end of the operating day, and a data logging microcomputer (connected to the door switches, engine, odometer, and wheelchair ramp) that controls the operation of the other components and creates data records while the bus is in operation.

The APC system includes infrared transceivers installed at each garage to continually monitor buses passing through the bus servicing lines and to automatically offload data from APC-instrumented buses to a wayside computer. The off-loaded data is then transferred to another PC in the Planning and Schedules Division, where it is matched to the schedules and stops database and stored permanently in a DB2 database. Passenger activity and running time reports are then generated from the DB2 database by Winnipeg Transit staff for service planning and scheduling purposes.

In 2004 an additional 13 buses were outfitted with APC equipment, in part to support the Advanced Transit Communications and Location System project, bringing the total number of APC buses to 73. These buses are rotated amongst all routes and assigned on all trips a number of times during each seasonal schedule booking period. This allows for 100% sampling of all trips, for all days of the week, with several observations for each, providing for a high degree of reliability in the data collected.

The system has been operational for three years. The on-board components and the equipment at the wayside stations at the garages have performed reliably. The system provides very accurate passenger traffic information throughout the entire system.

4. PROJECT DESCRIPTION

4.1 System Characteristics

The Advanced Transit Communications and Location System will include the following fundamental characteristics:

- Radio voice/data functionality and coverage that meets or exceeds current system capabilities.

- Hardware and software architecture that can be integrated with existing Winnipeg Transit information systems, that can accommodate future applications requiring additional data communications, and that can be cost-effectively acquired, installed, supported, and maintained by Winnipeg Transit.

- Automatic Vehicle Location using GPS, providing real-time bus location and schedule adherence information to be used for the following purposes:

  Operations
  - ❖ Aiding incident response by knowing actual bus location, speed and heading
  - ❖ Helping Bus operators maintain schedule by providing continuous on-board schedule adherence feedback
  - ❖ Assisting supervisory staff in regulating transit service and dealing with service exceptions, by providing reliable, system-wide service status information, such as schedule and/or route deviations
  - ❖ Enabling transit priority measures through traffic signal pre-emption for buses

  Traveller Information
  - ❖ On-board next stop automated announcements and visual displays
  - ❖ Real-time bus arrival displays at transit terminals and major stops
  - ❖ Dissemination of real-time schedule information via Customer Service Agents, telephone IVR systems, internet-based applications, stand-alone kiosks and various handheld devices

- Two-way text messaging between the Control Centre and buses, to enhance the distribution of information and reduce reliance on voice only

- Bus-to-bus communication to facilitate such things as passenger transfer requests

- Supervisor vehicle-to-bus communication, to enable direct communication between Inspectors and Bus operators

4.2 Planned Approach

The primary goal of this Project was to develop a GPS-based transit schedule adherence system that would minimize the amount of schedule related data needing to be transmitted between buses and the Transit Control Centre over the communication system and streamline the related data management at the Control Centre. The planned approach was to perform the schedule adherence calculations locally on-board each vehicle and to transmit information for only those buses that are not operating within a designated tolerance of the planned schedule. If a vehicle is operating within accepted tolerances, no data would be transmitted and the Control Centre would assume that the vehicle is operating on its planned route and schedule.

As most vehicles operate within the planned tolerances, this approach would reduce the amount of data to be transmitted to the Control Centre and would lower the required investments in central hardware and software. Additionally, and more importantly, this approach would avoid the capital investment necessary for the radio or wireless capacity and infrastructure needed to accommodate a fleet of 500 buses reporting data every 30-60 seconds to a central computer and the associated return messages to buses.

The Project involved the development and testing of such a system on 10 of the 73 buses already instrumented with APC equipment, which includes a GPS receiver, infrared transceiver, and on-board computer. The project approach was premised on the knowledge that additional units of this type could be supplied and installed at a cost that would make fleet-wide use for AVL economically practical.

This "Smart Bus" approach, with autonomous schedule intelligence on-board each bus, allows for up-to-the-second schedule adherence determinations to be made instantaneously, without the inherent delays associated with a "dumb" bus simply reporting its location/speed/heading to a central computer, and waiting for a schedule adherence determination to be made and then reported back to the bus. During this delay, even if only several seconds in duration, the status of the bus, in terms of its location/speed/heading, could change significantly, dependent on whether the bus is stopped (e.g. at a red light) or moving (e.g. 80 kph on an express route), rendering the incoming schedule adherence feedback report inaccurate.

Having schedule intelligence on-board each bus that is accurate and timely can:

- support Next Stop annunciation, where bus stops may be as little as 150 meters apart
- facilitate traffic signal priority for *only* buses running behind schedule
- Provide the Bus operator with meaningful, continuous feedback, whether stopped or in motion

As part of the Planned Approach, in order to support the AVL system and other new functions, such as text messaging, it was necessary to also replace the aging radio

equipment and driver interface units on-board buses, together with radio equipment at base signaling tower sites. The objective here was to continue to use existing radio frequencies and develop a new system that could seamlessly support both existing bus radios/functionality and new generation equipment and features as they would be phased in over 2-3 years.

Winnipeg Transit owns its own radio tower infrastructure and licensed radio frequencies in the 400 MHz band. These frequencies are well suited to both voice and data communication and provide excellent city-wide coverage. There are no airtime charges, such as are usually associated with commercial 800/900 MHz radio or with cell phone systems. Additionally, these technologies are not necessarily well suited to data, particularly 800/900 MHz radio, which may require a separate system for data transmission from voice communication. Maintaining the existing radio frequencies and upgrading infrastructure around this was therefore seen as the most cost effective, long term approach.

The final Transport Canada project component was the need to update the Winnipeg Transit Control Center CONTACT system, in order to also support AVL and other proposed new functions. Because of limitations and weaknesses in the CONTACT system, a decision was made to design and develop a completely new system instead. The Intracom system will replace many of the routine existing functions performed by CONTACT, and support all of the new system features, with flexibility to expand as these evolve.

4.3 Scope of Work

The Work constituting this project included the following elements:

a) Development of a modern replacement on-board radio Controller (microprocessor and software) for the existing radio signalling and control board used on Winnipeg Transit buses.

b) Development of a new Driver Interface Unit required to be integrated with the new on-board radio Controllers.

c) Development of a modern replacement of the radio controllers/modems used for communications between the Base Signalling Units and the Control Centre.

d) Development of a schedule loading system (hardware and software) using infrared (or other) technology to transfer the planned schedule for a run to the bus assigned to that run before the bus departs the garage.

e) Acquisition/installation of the new radio Controllers on the test fleet of 10 buses.

f) Acquisition/installation of a new Driver Interface Unit on the test fleet of 10 buses.

g) Acquisition/installation of new radio controllers/modems at two Base Signalling sites and at the Control Centre.

h) Acquisition/installation of new radios on the test fleet of 10 buses.

i) Upgrade of radio transmission infrastructure at one of the two base signalling locations.

j) Acquisition/installation of schedule loading system at two garages (Fort Rouge Garage and North Garage).

k) Field test of new radio controller/driver interface unit on the test fleet, new radio controllers/modems at two Base Signalling Units/Control Centre, and **existing** bus radios to replicate current bus communications functions of the existing bus radio system.

l) Field test of new radio controller/driver interface unit on the test fleet, new radio controllers/modems at two Base Signalling Units/Control Centre, upgraded radio transmission infrastructure, and **new** bus radios to replace current bus communications functions of the existing bus radio system.

m) Field test of schedule loading system. Prior to a bus's departure from a garage, the system will be required to load the planned itinerary for the assigned run of the bus. In addition, the system will be required to transfer data to buses in the field when run assignments are changed due to breakdowns, trade-offs, run reassignments, etc.

n) Development and installation of software on-board the buses to monitor location in real-time, to calculate schedule adherence, to define tolerances for acceptable performance, and to communicate exceptions from the planned schedule to the Control Centre via radio.

o) Development and installation of the software to upgrade the CONTACT system in the Control Center to manage the expanded set of data received from the test fleet buses and to incorporate that information into displays and reports used by Transit Service Controllers.

p) Evaluation of the operation of each of the developed components and project concept. Make recommendations regarding the design, operation and integration of all the hardware and software developed during the project.

5. DEVELOPMENT AND TESTING

5.1 Overview

There were various new components and functions developed during the project:

- Existing on-board UHF radio, handset and silent alarm microphone replaced with industry standard products
- Existing on-board radio controller/modem replaced by Infodev unit/software
- Existing on-board DIU replaced by Infodev unit/software
- Existing BSUs at repeater towers replaced by Infodev units/software
- New RF transceivers/modems installed on-board and at transit garage
- New schedule compression software application created by Infodev
- New schedule adherence "engine" software added to existing APC on-board data logger/microprocessor
- Existing central radio control and incident management system replaced by Winnipeg Transit *Intracom* system
- New real-time schedule deviation reporting and processing, text messaging and other advanced communication and service control functionality created by Infodev and Winnipeg Transit

Figure 11 depicts how the various components of the project development plan interact with one another.

5.2 On-board Radio Components

The initial work of the Project involved developing a modern replacement for the 25 year old Ferritronics radio signaling and control board. First this would be to interface with the existing GE radios and then followed by replacement of the radios with modern, off-the-shelf two-way radios commercially available. Also considered during this phase was the need for replacement or upgrade of the radio handset, external speaker and PA microphone used for the silent alarm feature.

In July, 2003 testing began with an analog version of a new on-board radio Controller produced by Infodev, on a bus with an existing radio. The design was limited to replicating the existing functions performed by the old control boards, essentially channel switching, incoming message acknowledgement and four types of outgoing message requests. *Figure 12 shows the existing Ferritronics control board and new Infodev analog Controller.*

Initial tests were successful in that the new Controller worked in harmony with the old radios. During testing it was observed that the audio quality was poor or even absent during 911 and silent alarm calls from buses. This was a serious deficiency and testing was temporarily suspended.

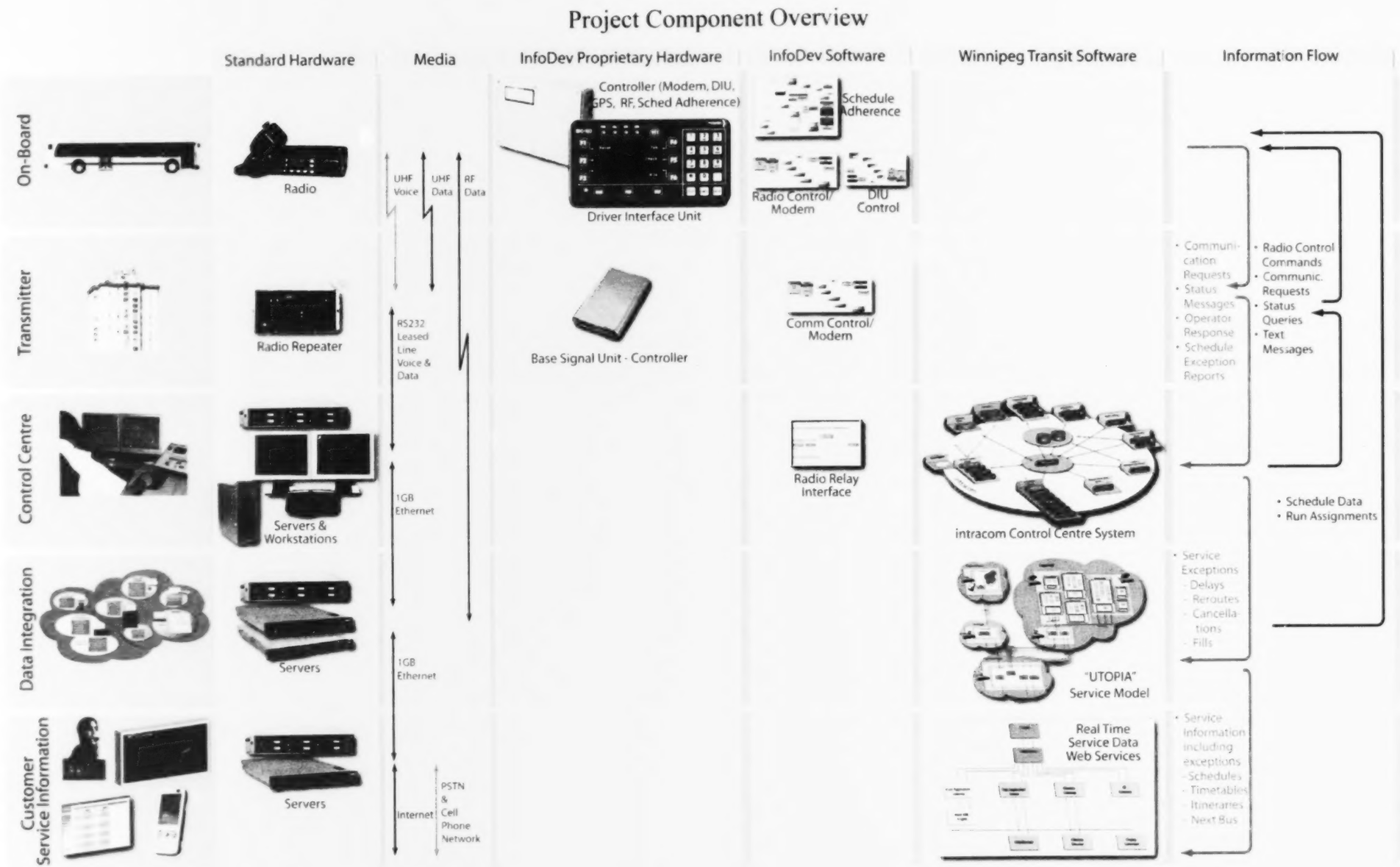


Figure 11 Project Development Plan

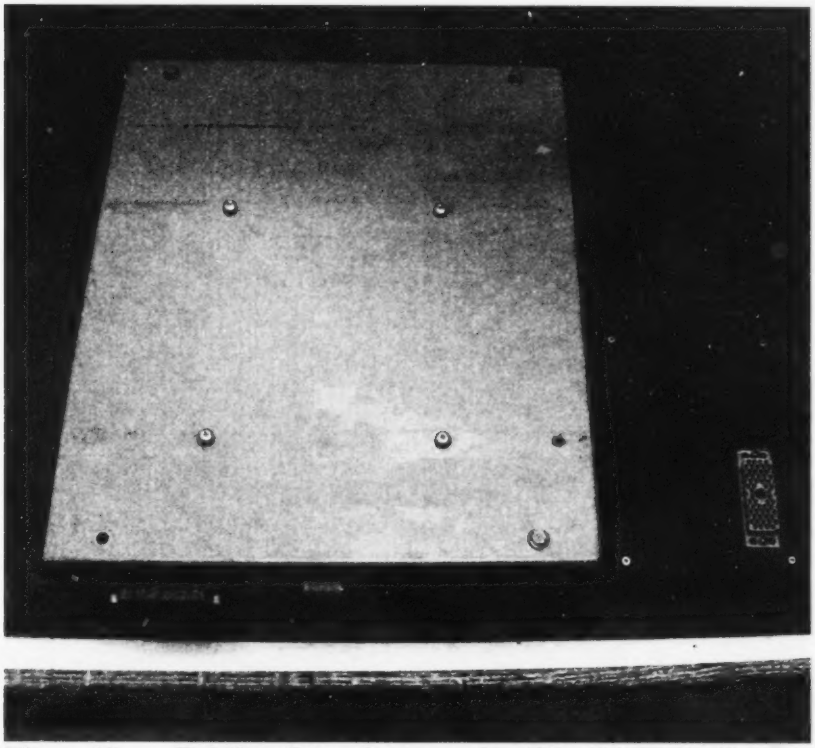


Figure 12 Existing (L) and new analog (R) radio controllers

A second generation analog Controller was installed in October, 2003, together with a new hands-free microphone for the silent alarm function and testing re-commenced. Audio reliability and quality was improved for Talk and 911 calls, however, noisy audio was experienced when the silent alarm was activated. This was determined to be caused by noise from the bus heater fans and windshield defroster fans used during winter months. The hands-free microphone was more prone to picking up these ambient sounds, compared to the more directional gooseneck PA microphone. The advantage of the hands-free microphone, however, was that by its design it could pick up voices from much greater distance, compared to the existing PA microphone, which unless directly bent in front of the Bus operator's face, could not receive anything discernable. While Operators are instructed to position the microphone in this way in case of an emergency arising, in practice very few do. *Figure 13 shows the location of the existing gooseneck PA microphone and the new hands-free microphone mounted in the top left corner of the overhead bulkhead.*

Figure 13 **Existing and new silent alarm microphones**
(Existing gooseneck PA microphone and new hands-free microphone mounted on the bulkhead left of the "Attention" signage)

Testing and ongoing development continued on four buses equipped with the second generation analog Controller and hands-free microphones from November 2003 to March 2004, with various modifications to remove unwanted noise. Reliability of the analog Controller was also monitored.

In March 2004, a first version of a new Digital Signal Processing (DSP) Controller was introduced by Infodev. This model used software to replace functions previously performed through hardware on the analog version. This design offers the ability to process data at much higher speeds, up to 9600 baud as compared to the 1200 baud speed of the analog version. The noise problem was improved through filtering techniques. The size of the unit was also reduced. *Figure 14 shows the analog and digital Infodev controllers in size relation to an existing Ferritronics control board.*

Initial testing showed the DSP Controller to be more reliable in service. However, overheating of the unit was discovered during very warm summer conditions with daytime temperatures reaching 30C or higher and temperatures inside the radio cabinet exceeding 40C. This caused the frequency of the radio to drift, resulting in calls failing. A temporary and partial solution was to simply remove the top cover from the DSP unit.

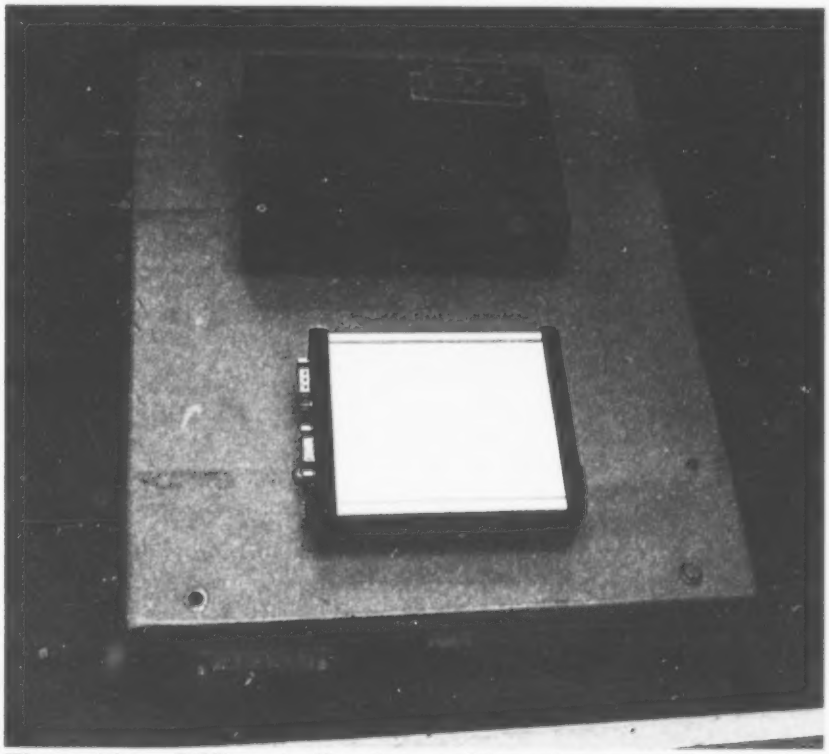


Figure 14 DSP controller shown with analog controller (black) and existing (grey)

At the same time as the DSP controller was introduced in March 2004, new Motorola CDM1250 radios were also installed and interfaced to the DSP. These radios are a standard product offering used elsewhere by the City of Winnipeg and are comparable to other makes on the market. New Motorola handsets were also purchased. The existing external speaker was retained, as its serviceability was satisfactory. By April 2004 all 10 buses were outfitted. The combination of new controllers and new radios worked seamlessly on this test fleet, replicating existing radio functions, and communicating with the existing Base Signaling Units (BSUs) at the two tower repeater sites. *Figure 15 shows the new Infodev DSP controller and new Motorola radio mounted in an on-board radio cabinet above the existing GE radio and Ferritronics control board.*

Figure 15 New (top) and existing (bottom) controllers/radios

Testing of the new DSP controllers and new radios continued through the summer and fall of 2004. In addition to the high temperature problem described earlier, other minor problems were experienced, such as radios not being reset properly by the DSP, causing calls for other buses to be received. These issues were addressed through several software versions released by Infodev and updated on the DSP. Operation eventually became quite reliable.

5.3 On-board Driver Interface Unit

The development of a new DIU was approached on the basis of considering several factors:

- Able to support existing radio call types
- Able to support planned advanced communication functions
- Flexible for future expansion of functions
- Configurable by Winnipeg Transit
- Durable for the on-board environment
- User friendly
- Compact
- Economical

The initial development of a new DIU was based on supporting the existing call types, both outgoing from the bus and incoming from the Control Centre. The first new DIU was installed in a bus for testing in March 2004, at the same time as the new DSP Controller and new radio was first installed. Shortly thereafter, the other nine buses were also outfitted. *Figure 16 shows the first release of the DIU, mounted on the left side of the driver's workstation.*

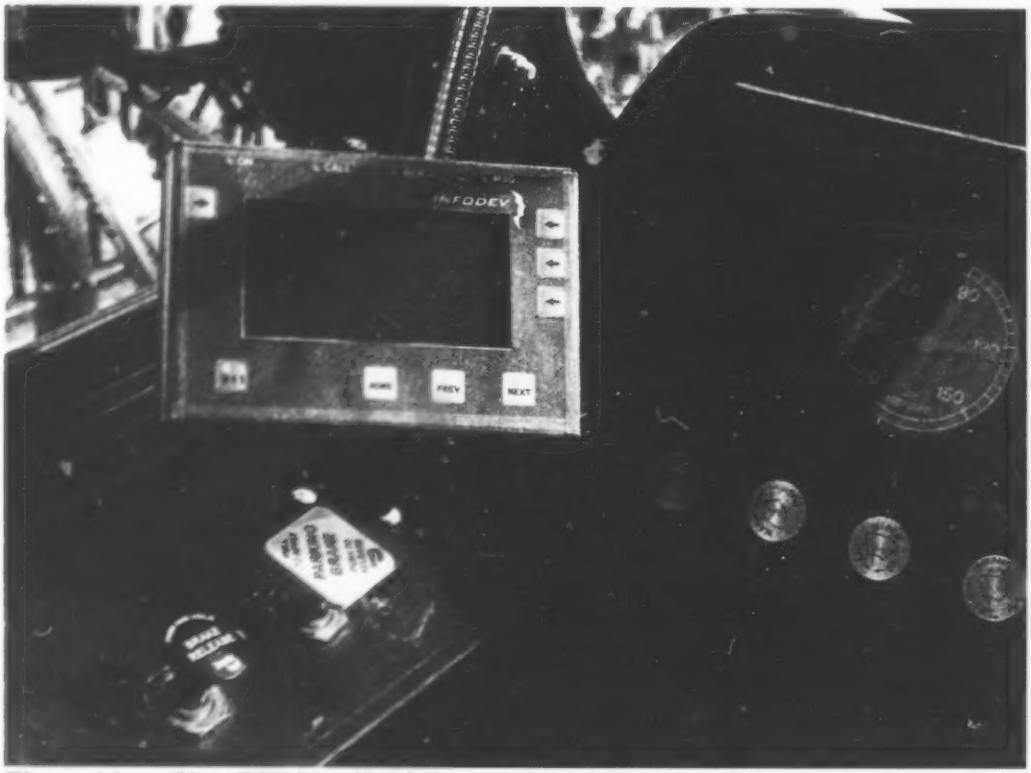


Figure 16 New DIU installed in operator's workstation

The DIU is interfaced to the new Controller, radio and data logger and is designated as the master control device of the various on-board communication/AVL system components.

The design of the DIU is such that through the use of buttons, menus and screen displays, the unit may be easily re-configured. The unit is small enough to allow for various mounting options. The screen display supports a variety of status message functions for the Operator, which indicate an incoming call and type, or to confirm an outgoing call request has been received by Control. Audio alerts and LED indicator lights are also features. *Figure 17 provides examples of status messages while a DIU is in use.*

The "Home" page displays the Reset, Talk and Check choices. Because a menu system using sub-screens was planned in order to support advanced functions, a separate "hard" button was provided for the 911 call type, so that this feature is always immediately available.

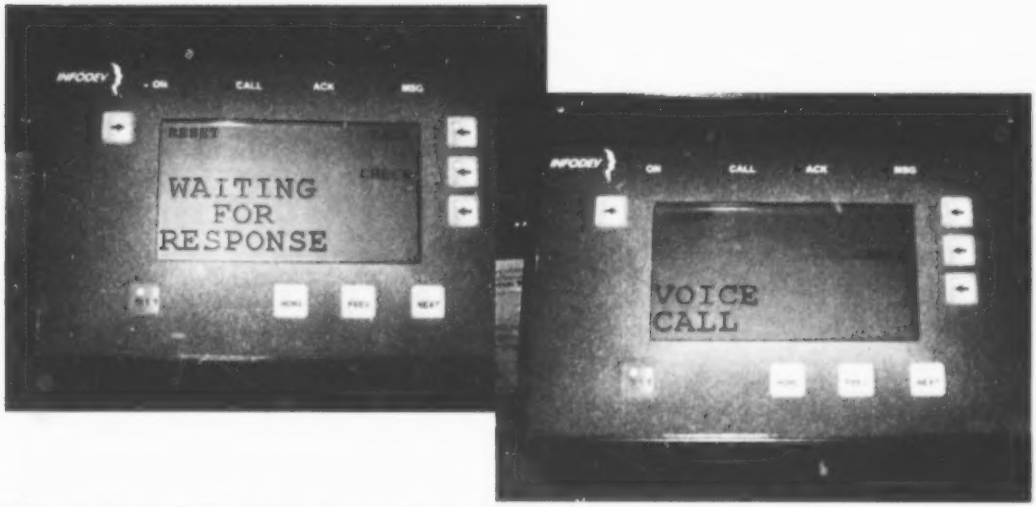


Figure 17 DIU status messages

During testing over the next four months, these 10 buses were able to communicate normally with the existing Base Signalling Units and the Control Centre CONTACT system. This represented a major milestone in project development work, as at this point a complete replacement of all existing on-board radio components had been successfully achieved. This is not to say there were not minor issues encountered, but these were resolved through software changes in the DIU or Controller.

5.4 Base Signalling Units

There are two radio repeater sites used by the radio system. Towers are mounted on the top of two tall buildings in downtown Winnipeg. Each of these sites houses a base station duplex radio and a Base Signalling Unit (BSU). Two voice channels and the data channel operate from each site. The BSU sends and receives data between the CONTACT system and buses. The BSUs are connected to the CONTACT system via telephone lines and modems.

In many ways the BSU is similar to the on-board Controller and hence the development of a modern replacement closely followed the experience gained from this work, which preceded this. The first new BSU developed was based on Digital Signal Processing (DSP) technology. One notable difference, however, relates to the BSU functioning during a silent alarm. When an alarm is received from a bus, the BSU will send out a busy signal to all other buses for one minute to prevent other call requests from coming in.

The first new BSUs were installed in July 2004 at one tower site. There were two units provided, one for the data channel and one for a single voice channel. These units were connected via telephone and modem, so that Infodev could access them remotely, via internet, from their Quebec office. This allowed the units to be activated/de-activated as needed and for messages to be sent out to buses for testing. Thus it was possible for Infodev to conduct testing at will and at times that would not be overly disruptive to normal operations. *Figure 18 shows the temporary installation of the new BSUs at one of the tower sites.*

The new BSUs were primarily designed to communicate exclusively with buses equipped with new DSP Controllers, for handling existing message types, and as well, for new message types associated with the Advanced Communications Project, such as AVL reports and text messages. While the new BSUs were capable of communicating with buses equipped with the older, existing controllers, for the most part these would continue to communicate through the existing BSUs.

Initial testing of the BSUs involved monitoring of radio communication traffic between buses and the existing BSU. Then simple test messages were sent to buses and acknowledgement received of successful receipt. In October 2004 the first text message, generated from a laptop, was sent from the BSU to a test bus. In December, a text message generated by the new Intracom system was sent via internet, to Infodev in Quebec, and then via dial-up connection to the new BSU and out via radio to a test bus. By February, 2005 direct access to the BSUs from Intracom was possible and a test of voice calls to buses and short text messages were made.

Testing continued through May 2005 with the test buses in the field. Voice communication performed normally. However, the text messaging function met only with moderate success. While very short text messages could be sent to buses, longer messages were corrupted. This was in part due to data "collisions" occurring on the data channel, caused by simultaneous traffic between the existing BSU and other buses. In addition, the speed, synchronization and harmony between the new BSUs and new on-board Controllers was thought to be less than optimal.

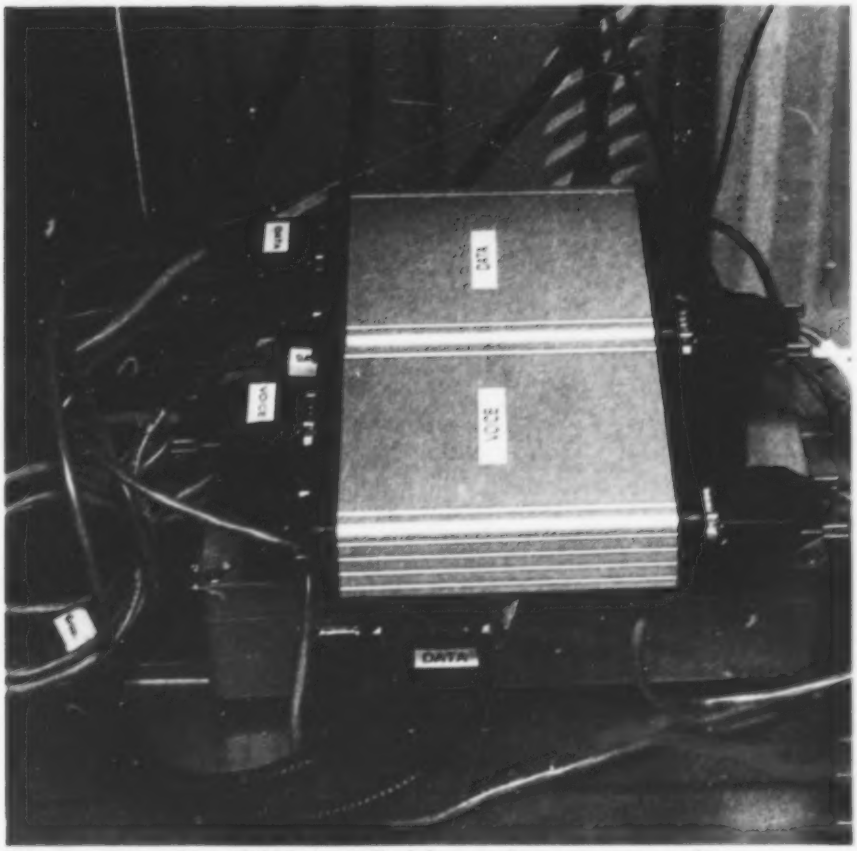


Figure 18 New BSUs installed for testing at a tower site

5.5 Schedule Compression

The basis for the Advanced Transit Communications and Location System Project was an AVL system which could perform the schedule adherence calculation locally on-board each vehicle. In order to do this, it is necessary for a bus to know what its current schedule is. Buses are assigned to routes on a once or twice a day basis. During the course of a day, a bus may experience a problem and need to be "traded off", or replaced with another bus, which again will require a current schedule.
The approach used was to devise a means by which the schedules for all runs, for all days of the week, could be loaded onto every bus, such that buses could be used with maximum flexibility. This approach was also seen as minimizing the daily volume of data to be transferred to buses as they are assigned to runs, which otherwise could delay dispatch operations.

Four times per year transit schedules are adjusted seasonally, resulting in new master schedules for all runs. Switch over from one season, or "booking", to another occurs on a

Saturday night. This creates a need to update the schedules on all buses in a very short time frame. Thus it was decided that it was desirable to have, not only the current booking on-board, but also the upcoming booking several days before the changeover, to eliminate the possibility of buses not being updated in time, due to a system problem or bus unavailability.

There are approximately 1000 different weekday and weekend runs, each with its own schedule, contained in the master schedule for each booking. The HASTUS scheduling software is used by Winnipeg Transit. The data file for each run is comprised of a series of one-way "trips", made up of a sequence of timing points. Each timing point, of which there are about 600, has a unique number, a descriptive name, and geographic coordinates using latitude and longitude (often known as X and Y coordinates). Timing points are uni-directional, i.e. they only serve one direction of a route. A location that is a timing point for both directions of a route will have separate coordinates for each side of the street or corner of the intersection. For each trip, there are scheduled arrival and/or departure times for each timing point, as well as distances and running times between timing points. There are also garage pull-out and pull-in times/locations and various deadheading times.

Together, a complete master schedule represents approximately 80 megabytes (MB) of data. This requires considerable memory space. Also, the transfer of a file of this size, using infrared, radio frequency or some other wireless technology, could be difficult or time consuming. Hence, a method of compressing the schedule files was identified as a key project deliverable.

Through their expertise in this area, Infodev was able to develop an algorithm that compresses the 80 MB schedule file down to just 64 K (kilobytes). This minimizes the on-board storage space required, even for two bookings and facilitates rapid data transfer. When a run is selected from this file and assigned to a bus, the compressed file is "unzipped" for use by the on-board schedule adherence computer.

This work progressed through the fall of 2004, with Infodev conducting tests in their lab on the accuracy of the compression algorithm. By October, Winnipeg Transit was provided with a small PC application that held a complete compressed schedule file. Winnipeg Transit was able to "unzip" data for analysis. Particular attention was paid to "interlined" runs, or runs that have a bus perform trips on more than one route during the course of the day. This helped identify and later resolve some problems associated with runs that contained trips for such things as employee shuttles, school buses and industrial chartered service, where only beginning and ending timing points existed in the master schedule, regardless of the routing distance and running time.

With these problems addressed, the compressed vehicle schedule (CSV) file was found to be 100% accurate, compared to the master schedule.

5.6 Schedule Loading

Each of the 10 buses used in the Project were from the pool of 73 Winnipeg Transit buses equipped with the Infodev APC system. A key component of this system is an on-board data logger, which is a versatile, rugged automotive frame microprocessor. It is used in the APC system to log all boarding and alighting activity of passengers, detected through infrared (IR) sensors, against GPS coordinates and time. *Figure 19 shows the on-board data logger with a new radio and controller.*

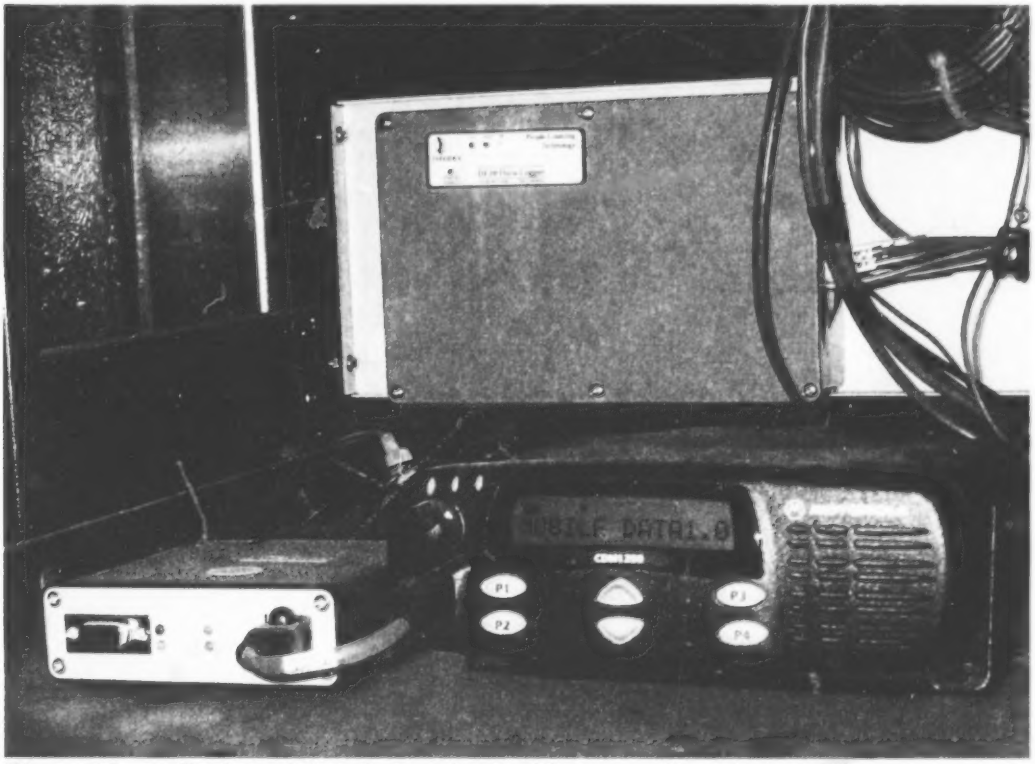


Figure 19 On-board data logger (top) with new radio and controller

The data logger would be used to store the schedule file for the on-board schedule adherence system. In order for compressed schedule files to be loaded into the data logger, a method of transferring the data while buses are parked at the transit garages, needed to be developed. Optimally, a wireless, automatic system was desired.

Infodev has considerable experience in the use of infrared (IR) technology for this purpose and had been employing this means for several years to load and offload data on a daily basis from the 73 APC buses. For this reason, IR was chosen as a proven and effective technology to use. The 10 buses being used for the Project were already equipped with the necessary transceivers, as were both of the garages.

As buses pass through the service lines each day for fuelling and cleaning, they are stationary for several minutes. The IR transceivers are precisely positioned in the garage to align with those on-board the buses. Data transfer normally takes about 1-2 minutes. *Figures 20 and 21 show the IR transceivers in the garage and on an APC equipped bus.*

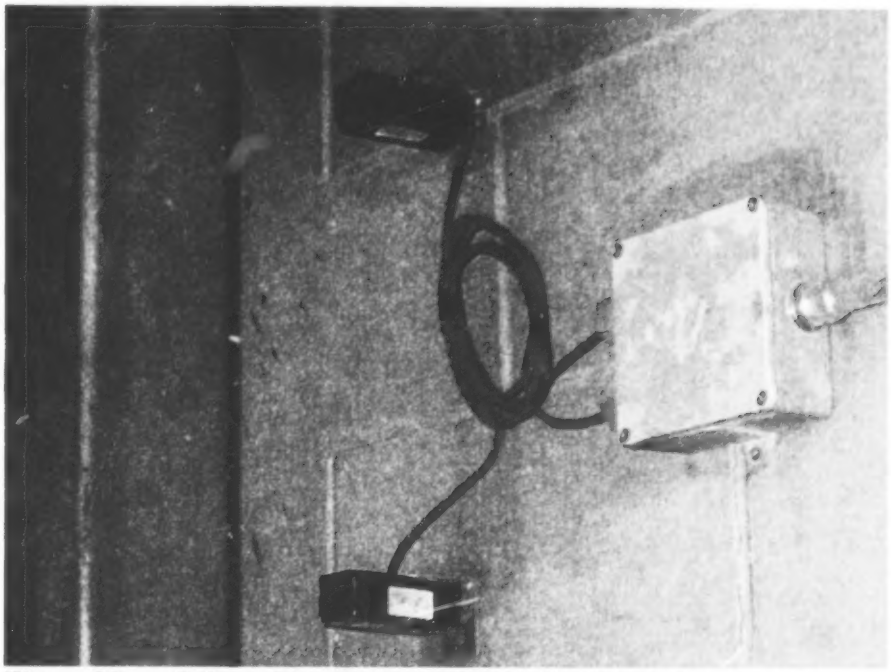


Figure 20 Infrared transceivers mounted in the garage

The on-board IR transceiver is connected to the data logger and DIU. The IR transceivers in the garage are connected to a PC in the garage, which in turn is connected to the Winnipeg Transit network. Infodev can also remotely access the garage PC. Through program routines, buses can be queried to download stored data, or be sent new program files, with a record of all these transactions kept.

The first upload of a compressed schedule file from the Transit network to a bus, via IR, was successfully accomplished in November 2004. Subsequent tests included file transfers directly from Infodev's office in Quebec. At this stage in the project, the compressed vehicle schedule was only viewable using a laptop computer connected to the data logger. However, this confirmed that a complete and accurate file transfer took place and that any run could be unzipped for use.

Figure 21 Infrared transceiver installed in the side window of a bus

Later, in subsequent testing during the Schedule Adherence development phase, a problem with IR was detected. As can be seen from Figure 19, the IR transceiver is quite exposed to sunlight. It was found that sunlight created false data transmissions from the IR transceiver to the data logger and DIU, which disrupted other data flows occurring between the data logger, DIU, controller and GPS receiver. A temporary resolution was to disable the IR during daylight hours using software.

The next step was to provide a means to tell a bus what run it is assigned to before it leaves the garage, so that the applicable schedule could be unzipped for use by the schedule adherence system.

It was preferred to do this automatically, rather than through manual entry by the Bus operator, in order to reduce errors and omissions. Other Winnipeg Transit systems already support the bus dispatch process and the bus assignment files are readily available electronically.

IR was seen as a good mechanism for loading the run assignment for those buses serviced overnight and leaving the garage in the early morning. However, this did not cover all situations. Many buses are assigned to a run in the morning rush hour, then return to the garage and are later re-assigned to a different run in the afternoon rush hour. They are not necessarily serviced in between. Yet other buses are dispatched directly from various maintenance areas of the garages, and do not go through the servicing line first. Where

these buses are parked and then later exit the buildings is not conducive to IR transceiver placement.

Because of these issues, work began with testing of RF (radio frequency) spread spectrum modems in June 2005. Infodev and the City of Winnipeg had experience with RF technology from other projects. RF works on line-of-sight within an approximate 1 km radius. The modems were developed in the 2.4 GHz frequency range, which is an unlicensed, public band.

The approach would be to place a few of these around the Winnipeg Transit property (and one on each bus) to achieve complete indoor and outdoor coverage. These units are very compact and can be mounted in many different locations. The RF modems at the property would be linked to a PC which would be connected to the Winnipeg Transit network, just as the IR system is. The RF modem on the bus would be linked to the data logger. Vehicles would not need to be stationary, but the data logger would need to be powered on. Data can be continually broadcast, such that when a bus is started and the data logger activated, the transfer would be received then. *Figure 22 shows the size of an Infodev RF modem.*

Figure 22 Infodev RF spread spectrum modem

In August 2005 several buses were outfitted with RF modems and one was installed in the garage service line area. Data transfers between the bus and garage modems, from considerable distance was immediately demonstrated. *Figures 23 and 24 show the RF modem mounted in the garage and on a bus, respectively.*

This then also demonstrated that the daily or twice daily transfer of run assignments to each bus before leaving the garage could be done using RF technology as an alternative to IR.

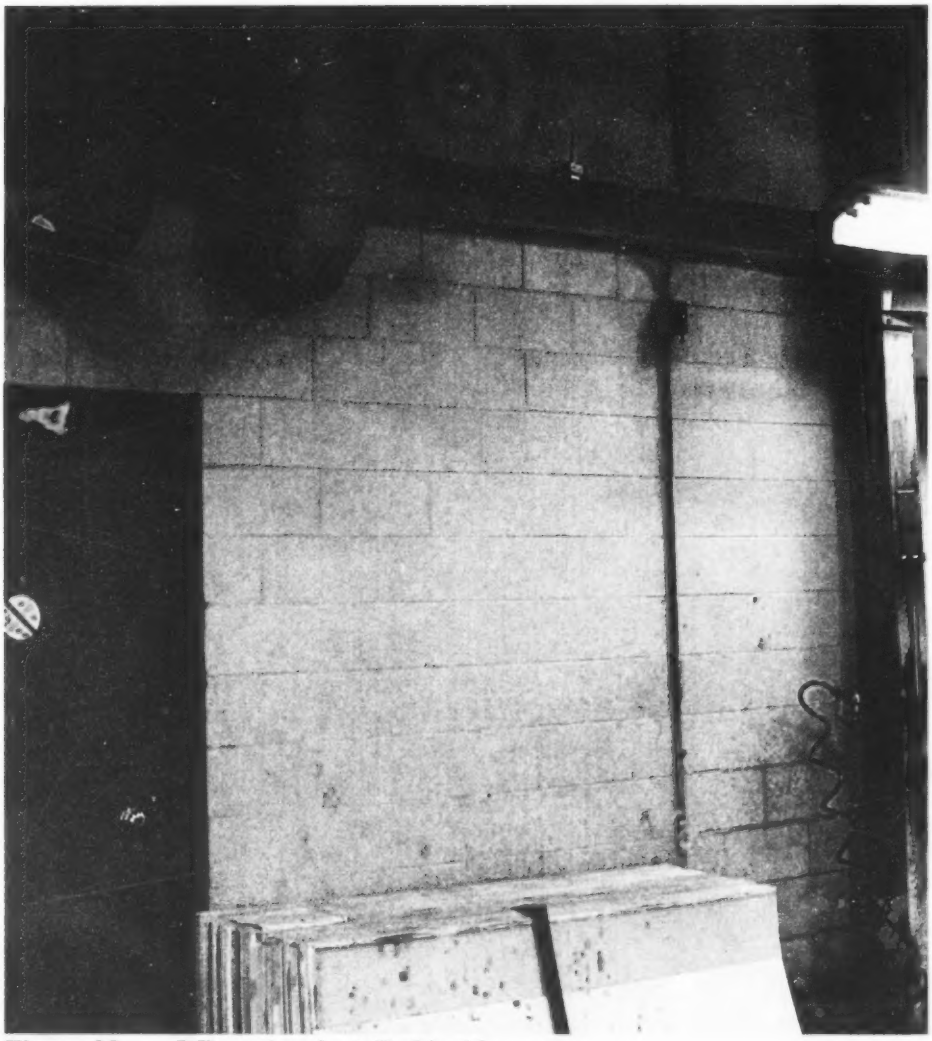


Figure 23 RF modem installed inside garage

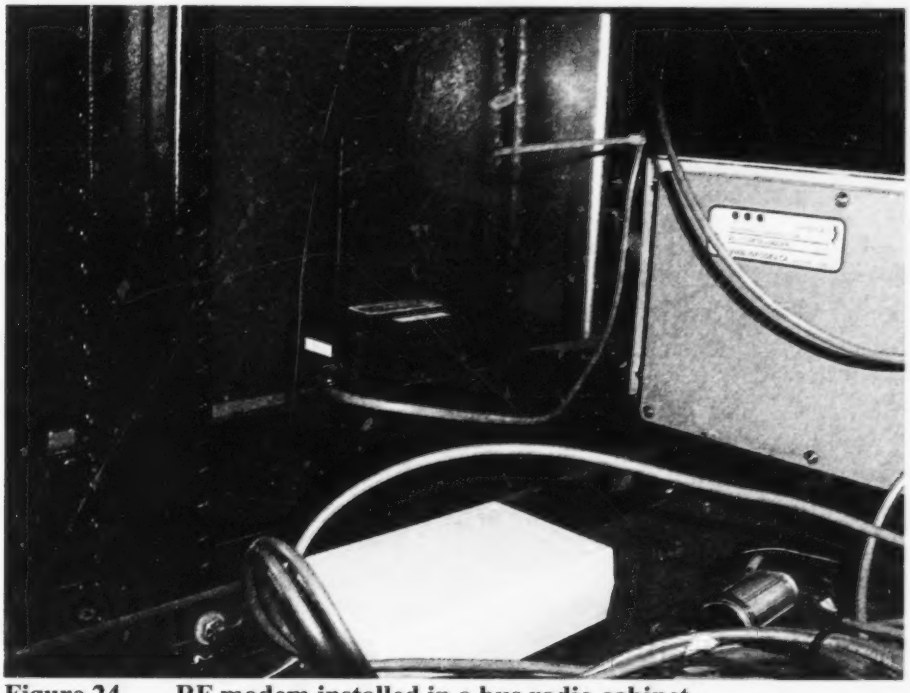


Figure 24 RF modem installed in a bus radio cabinet

The final Schedule Loading issue was to address the need to re-assign a bus to a different run while it is already out in the field, such as may be required in the event of a mechanical breakdown or for many other reasons. It would allow the replacement bus to also perform on-board schedule adherence and assist the Bus operator with schedule information. Again, it was preferred to do this automatically, rather than through manual entry by the Bus operator, to eliminate errors and omissions. However, a manual input function, password protected perhaps, was contemplated as desirable for testing, trouble shooting and for back up in the event of some system problem. This capability was therefore included as a future DIU feature.

The bus radio system was seen as the best way to remotely re-assign buses to runs. Usually this situation only involves one bus at a time. Since these buses would be running and have their communication system active, a data message could be sent out over the data channel with the run assignment. This would not create congestion on the radio system given the relative infrequency with which this would occur. However, in order to be able to do this, the new Intracom Control Centre system would need to have a function to support this.

Development of Intracom is covered in a later section. However, successful testing using the radio system to make run assignments for the on-board schedule adherence system was completed in June 2005.

5.7 Vehicle Location and Schedule Adherence

As has been discussed, each of the 10 buses used in the Project were from the pool of 73 Winnipeg Transit APC buses and were therefore already equipped with a GPS antenna and receiver. From experience with the APC system, it was known that the GPS system offered accuracy within a few meters and that good signal reception could be obtained throughout the city, including in the downtown area among the tall buildings.

The GPS receiver is interfaced to the on-board data logger. In the APC application, the data logger records data about the location and time of customers boarding and alighting, using door sensors and the GPS signal. This data is later off-loaded and software is used to match the files to the schedules and bus stop database. For the schedule adherence aspect of the Advanced Transit Communications and Location System Project, the goal was for each bus to autonomously determine, in real-time, exactly where on its route it is and how it is performing compared to its schedule. The process of matching location and time to schedules and stops would be performed by the on-board data logger.

For other vehicle location applications, e.g. emergency response, the raw GPS data (bus location, speed, heading) would be imbedded in the data portion of all voice communications from the bus to the Control Centre, where this information would be processed by Intracom and used by supervisory staff.

As discussed in Sections 5.5 and 5.6, the complete schedule for all routes/runs, in compressed format, could now be loaded onto the data logger. The individual schedule for each run could then be "unzipped" or opened by telling the data logger, through a variety of means (IR, RF or bus radio) what run value to use. The data logger is interfaced to the GPS receiver and to the DIU, bus radio and Controller. The data logger also receives inputs from the bus odometer. The challenge was to create a software application that could compare these sources of data and accurately determine the schedule adherence, or schedule "deviation" of the bus.

The schedule adherence "engine" developed by Infodev uses an algorithm that provides *actual* schedule deviation at timing points and *predicted* schedule deviation when between timing points.

Each route/run has several locations designated as timing points for scheduling purposes. These are typically at the ends of the route and at significant stops along the way where main roads and other bus routes are intersected. On average there is approximately 10-15 minutes of running time between timing points, and a number of intermediate bus stops served. In the schedules database (and hence in the compressed on-board schedule file), each time point has a name, number, routes served and latitude/longitude coordinates.

Once the run value has been set for the bus in the data logger, the system begins comparing incoming GPS location coordinates with those that exist for each timing point on the run. A radius can be defined around each timing point, dictating how close a bus

must pass a timing point to "acquire" it. When the coordinates from the GPS signal match those in the run schedule database for a certain timing point, within the set tolerance, the system registers acquiring the timing point. It will then select the closest time in the run schedule for that timing point, from all the trips that pass by that location. The system will now begin looking to match the next timing point in sequence for that run. It will ignore other timing points it may "see" along the way. When the second timing point in sequence is acquired, the system now knows exactly where it is in the schedule. The schedule adherence engine becomes active and the *actual* schedule deviation is calculated by comparing the current GPS time (accurate within milliseconds) with the scheduled arrival time for that timing point. This deviation is shown on the DIU in minutes and seconds, either as a positive number if the bus is ahead of schedule, or a negative number for behind schedule i.e. late. *Figure 25 shows a DIU home page displaying a schedule deviation (a delay).*

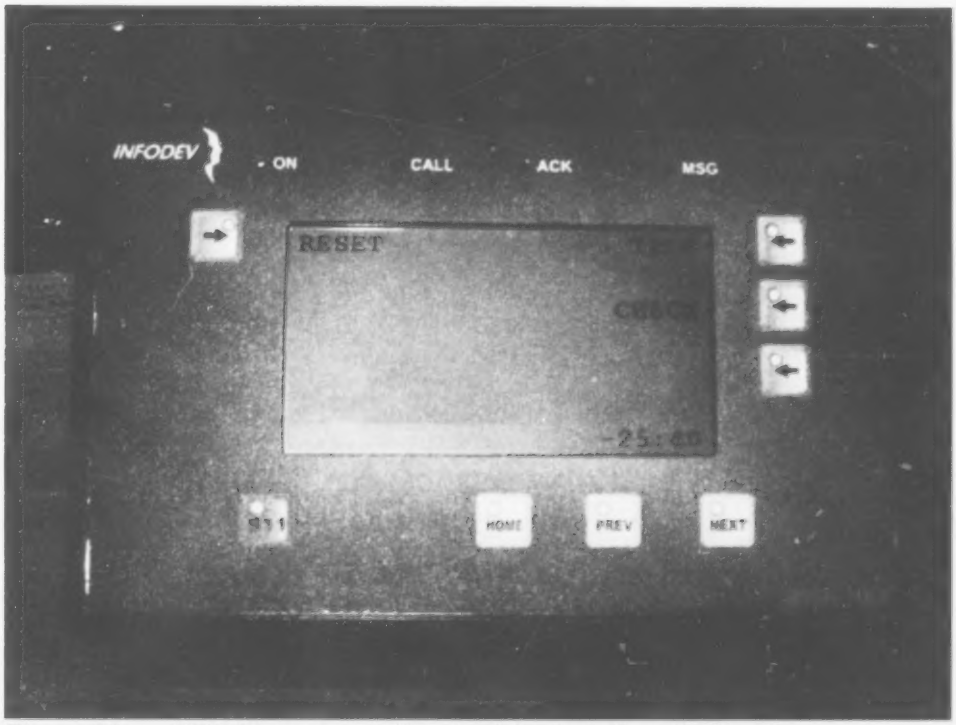


Figure 25 DIU home page with schedule deviation displayed

The system knows the next timing point in sequence to expect and also knows, from the database, the distance to reach it and scheduled running time to do so. The system monitors the progress of the bus proceeding towards the next timing point by receiving electronic inputs from the bus odometer, indicating distance travelled, while concurrently receiving time updates from the GPS signal. A *predicted* deviation is then calculated and recalculated every few seconds using this information. When the bus reaches its next

timing point, the deviation is again re-calibrated to *actual*, and the process started again. The DIU is used to continuously display the schedule adherence information to the Bus operator to assist him/her in following their schedule. The basic premise is to operate as close as possible to a zero deviation.

The Project used two levels of detail to display information to the Operator. First, the simple "+/-" time display in the bottom right corner of the home page as shown in Figure 23. The second was a run detail page showing:

- run number
- service type (weekday, Saturday or Sunday)
- current GPS time and schedule deviation
- last/next timing points and scheduled times
- distance and time to next timing point, in meters and seconds (total, covered, remaining)

Figure 26 shows the run detail page.

Figure 26 DIU run detail page

In the event that a timing point is missed, for example due to a detour caused by an accident, the schedule adherence system will continue functioning and look for the next following timing point to be reached. Should this not occur within a defined time period,

the system will reset itself and again begin searching for two sequential timing points in the run schedule in order to correctly identify what the bus is doing.

Schedule deviation reports are generated automatically by the system when set parameters are exceeded and sent from the bus to the Control Centre via radio. In future, it will be possible that these parameters can be changed dynamically by Control, dependant on conditions. For Project testing purposes, the system was configured to send deviation reports if a bus was more than five minutes late or more than two minutes early, which reflected Winnipeg Transit operating protocols and reporting requirements for Bus operators. These conditions had to exist for one minute before a report would be generated. This ensured that the deviation was not a momentary occurrence. If the deviation increases, additional reports are sent at one minute increments, after existing for 30 seconds. Similarly, as deviations decrease or fall within parameters, reports are sent to Control. Deviation reports can also be generated if the bus does not reach a timing point within a range of the expected time or distance to do so, or if schedule adherence is lost. As will be discussed, it is the new Intracom system that will receive and process these schedule deviation reports.

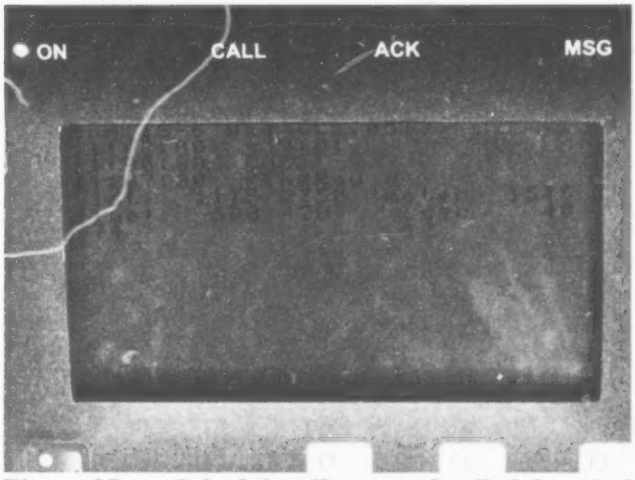
Testing of the schedule adherence system began in March 2005. The compressed schedule for the winter booking period had been loaded to the on-board data loggers. Test runs were selected and run values set via radio using a command from the Intracom system. Buses were then driven along the routing for the run, starting at any random point. When the system recognized a timing point for the run, this was indicated by a simple asterisk (*) on the run detail DIU screen. The system would then show the closest time in the schedule for that timing point and direction. Once the bus reached the next timing point this was again displayed by an * and the system was correctly able to verify where in the schedule the bus was and accurately calculate the schedule deviation between scheduled and actual. As the bus then continued, the deviation was updated every two seconds, predicting when the bus would arrive at the next timing point based on distance and time elapsing. For example, when stopped, a delay deviation steadily increased, but when the bus was operating above approximately 20 kph it declined.

Figure 27 explains the typical schedule adherence information displayed on the DIU.

During these tests, deviations exceeding the set parameters for being considered on schedule (-5 minutes/+ 2 minutes) were automatically reported via the bus radio system to the Control Centre where they were received by Intracom.

Tests were conducted on various routes/runs, with generally good results. It was found that a timing point could be passed at considerable speed and the GPS system could still acquire it. Timing points could also be acquired in the second or third lane of traffic. However, some issues arose when several timing points were located close to one another, causing the schedule adherence engine to become confused, or if a bus passed close to a correct timing point prior to arriving at it. In another case, the GPS system

seemed unable to consistently acquire one downtown timing point between tall buildings, perhaps because of signal obstruction.



Run # 16-6, weekday
- Current time 11:42:00 am
- Deviation 39 mins, 1 sec late
- Last timing point COS (Corydon & Osborne Southbound) 11:00:00 am
- Next timing point KingRow (Kingston Row) 11:07:00 am
- Distance to next timing point 2750M, covered 1575M, remaining 1175M
- Time to next timing point 420 secs, elapsed 40 secs, remaining 380 secs

Figure 27 Schedule adherence detailed description

5.8 Intracom System

As earlier described in this report, the existing 10 year old CONTACT system that supports bus radio communication and Control Centre operations, was a robust system that offered many advanced features. However, the system was not capable of supporting advanced communication functions such as real-time schedule adherence and text messaging, without major reprogramming. In addition, the system was dependent on all components working and the local area network (LAN) connections being available, otherwise a complete system failure occurred and even core functions, such as maintaining basic voice communication functions, was lost. In addressing these issues and considering the desire to add enhanced functions beyond the scope of this Project, a decision was taken to construct a completely new system, rather than invest in trying to modify the old. *Figure 28 depicts the Intracom system model.*

Intracom has been developed by a team of Winnipeg Transit Information Systems (IT) professionals over a period of 18 months, working closely with the end-users and with Infodev development staff. It is a client-server based system, utilizing PC technology, the JAVA programming language and the Eclipse development environment. It retains many of the basic communication and incident management functions of its predecessor, however enhances these in several ways. It will fully support the on-board schedule adherence system, managing incoming deviation data and assisting Controllers in understanding and processing this information, and passing it to traveller information systems. It will also support several advanced functions.

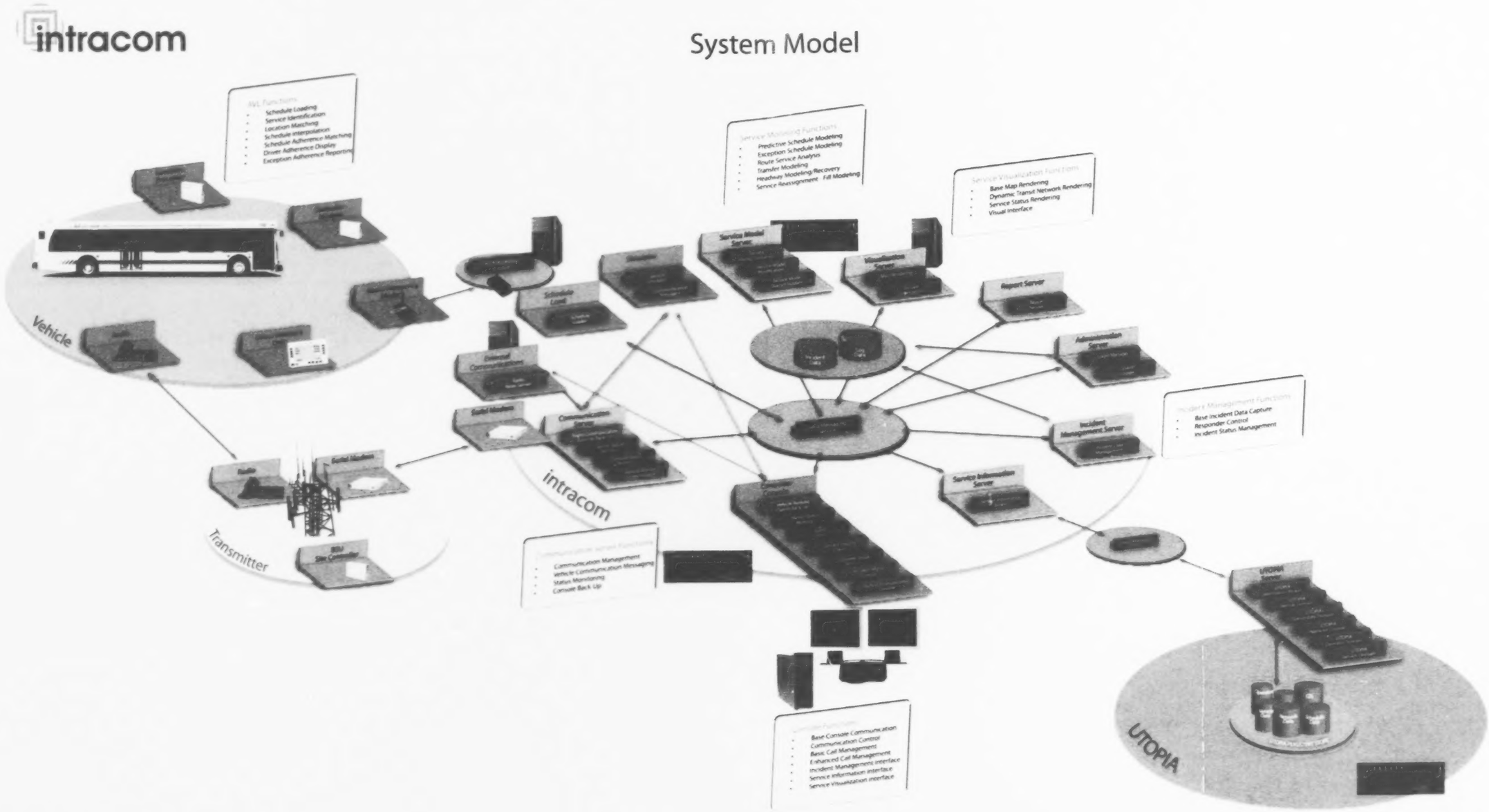


Figure 28 Intracom system model

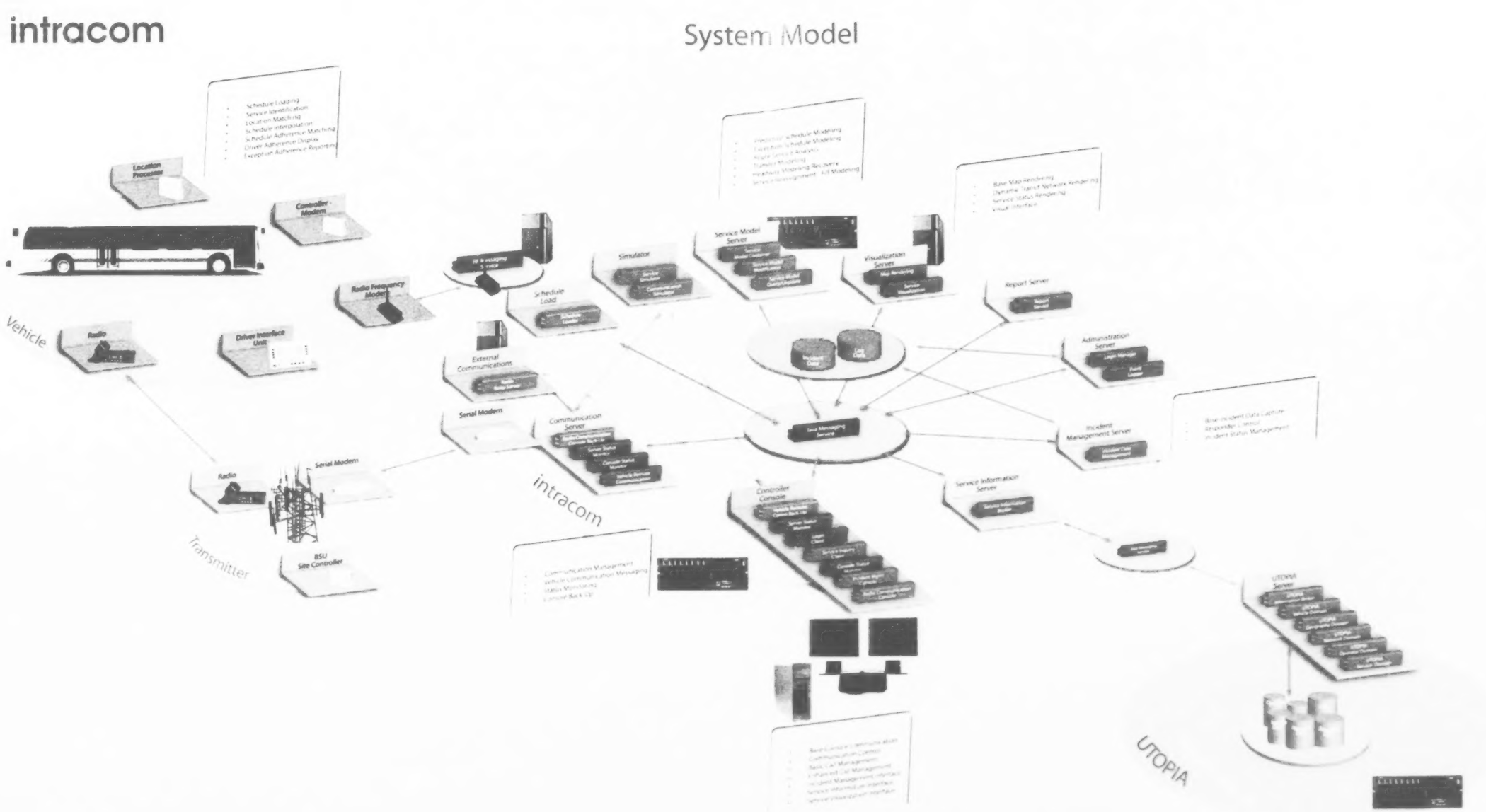


Figure 28 Intracom system model

Within the overall Winnipeg Transit project, this included intelligent and intuitive new tools for "service modelling" and "service visualization" that will use the incoming real-time fleet status reports and the other service data available to Intracom to analyze service delivery and provide recommended solutions to address widespread delays and disruptions that would be well beyond sole human intervention.

At a basic level, the stability, responsiveness and availability of the Intracom system has been increased through the use of modular construction, using loosely coupled, asynchronous communication between components. There is no requirement for a complete back up system (i.e. a master-slave configuration) as Intracom has built in failover and graceful degradation in the event of the loss of a given component. The failure of one component can not cause the failure of the system as a whole. Moreover, core hardening ensures that basic voice communication functions with the fleet can continue even in the face of disruptions to other parts of the system or unavailability of the LAN.

Intracom uses a new graphical user interface that is customizable and geared toward multiple monitor configurations. It effectively integrates real-time information from the bus on-board components with the back end information systems supporting operations and customer services. There are map-based features that combine street and transit network information with aerial photographs to give Controllers an easy to use tool for interpreting on-street incidents and specify such things as detours for bus routes and meeting points for response vehicles. Each time that voice communication takes place between a bus and Control, GPS and schedule adherence data will be transmitted to Intracom and displayed graphically for the assistance of the Controllers. *Figure 29 is a sample of a map-based graphical display.*

The bus communication system, supported by Intracom, will continue to rely on four call priority types from buses: silent alarm, 911, Talk Request, and Check. Intracom will manage and display these incoming calls. However, an enhancement has been made to parameterize Talk Requests, both in Intracom and the on-board DIU's, to allow further specificity by the Bus operator and subsequent prioritization by Intracom. For instance, Talk Requests can now be sub-defined as a mechanical problem, fare dispute, overloading or lost property report. *Figure 30 shows the Intracom call management user display.*

Outgoing calls to buses can continue to be initiated with just one bus, with groups of buses or with all buses in service. However, destination definition for group calling has been enhanced, allowing for fast communication, both voice and text, with specific groups of buses by route, bus stop(s) served, or other criteria, instead of using an All Call. This is expected to heighten Operator attention to messages, by reducing the number they receive but increasing their relevance.

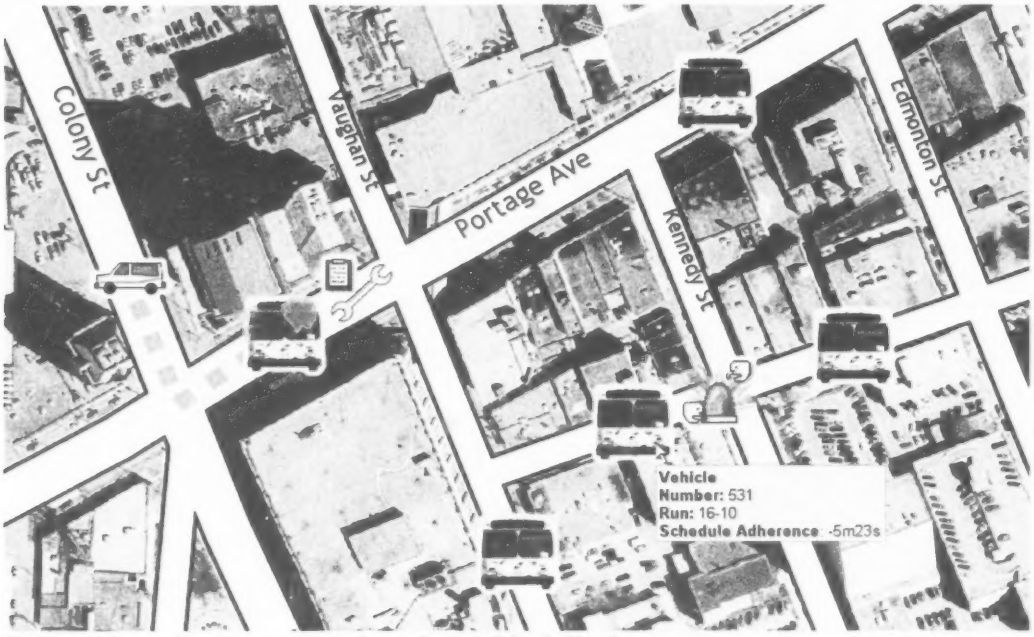


Figure 29 Intracom map-based graphical display

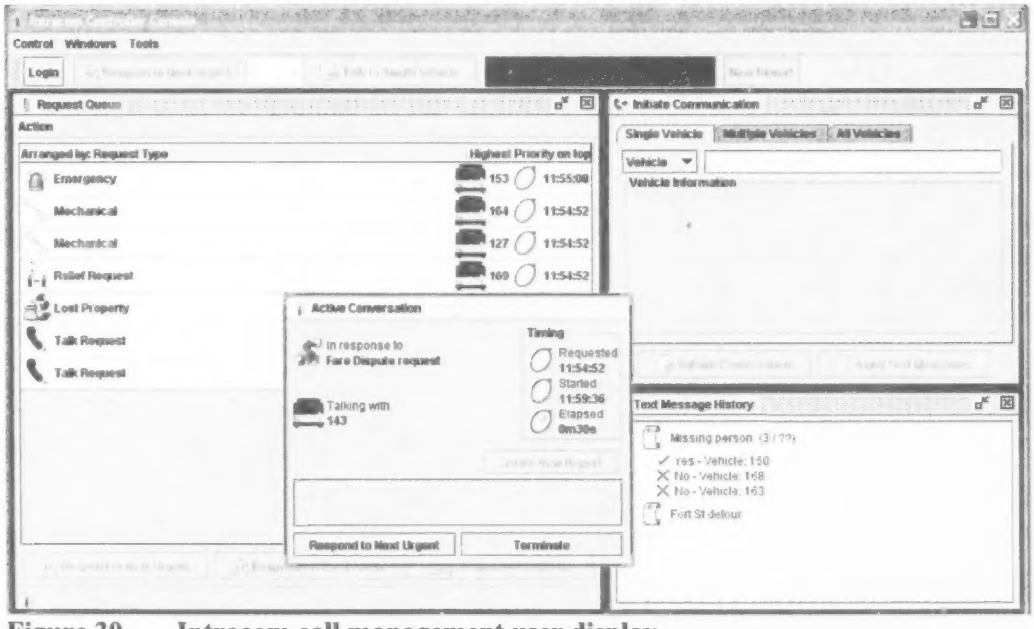


Figure 30 Intracom call management user display

Incident management functions in Intracom use a notebook approach which organizes information for timely response and tracks all details. There are various drill down, search and data manipulation features allowing Controllers to better access history, analyse trends and respond appropriately. *Figure 31 shows the typical user interface for a list of ongoing incidents.*

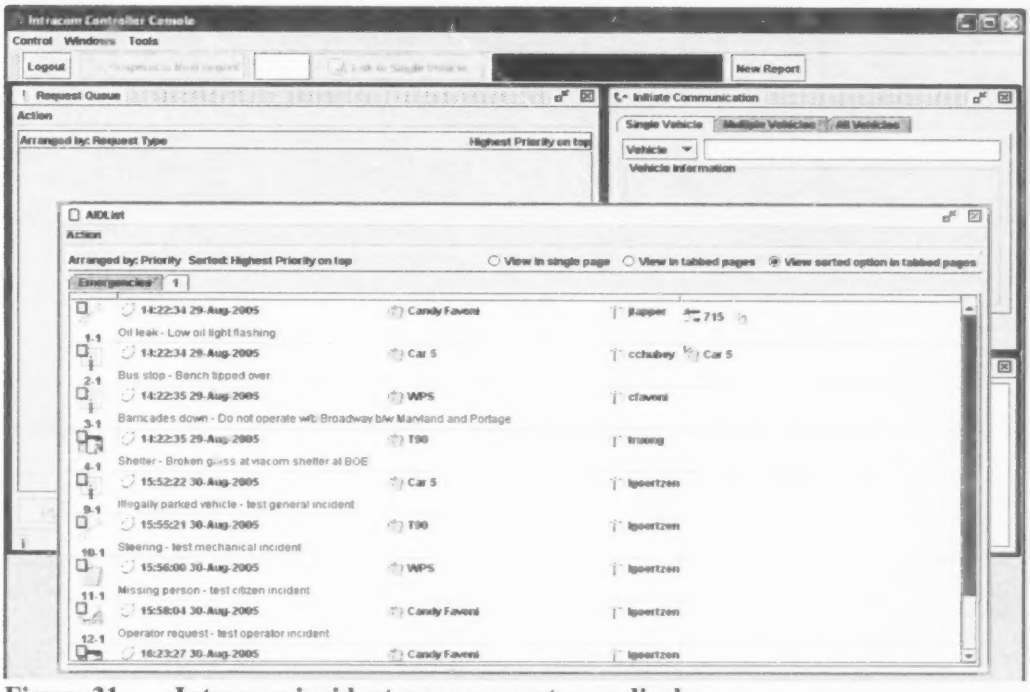
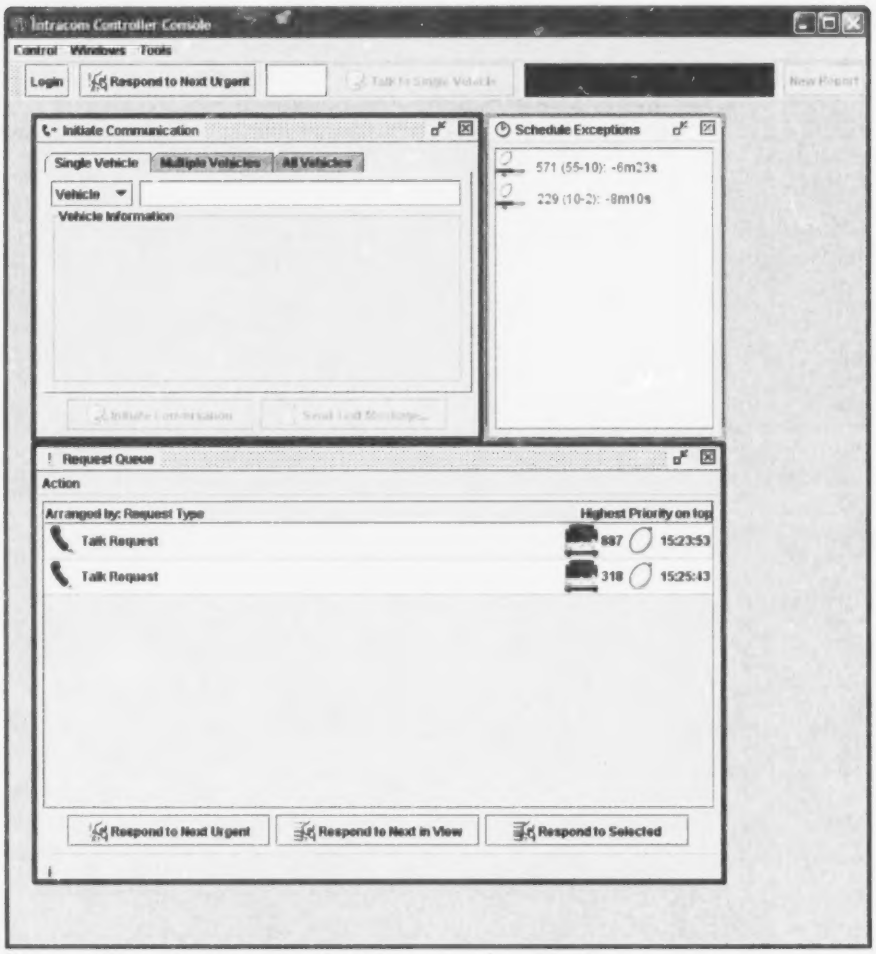


Figure 31 Intracom incident management user display

Focusing now on vehicle location, specifically real-time schedule adherence, Intracom receives incoming schedule deviation reports from buses, generated automatically by the on-board system, once the pre-set parameters have been exceeded. These reports can be displayed to Controllers for monitoring purposes or follow up, to determine the problem an initiate corrective action.

Intracom can also automatically process deviation reports and provide the data to other backend systems, such as Telebus, iSchedules and *Navigo*, without the need for Controller involvement, as had always been the case in the past. While an interface has long been in place to pass delays reported by *Bus operators* through the existing CONTACT system to these traveler information sources, this required a Controller to first create an incident report. At busy times this can become logistically difficult or impossible. Intracom can do this automatically, handling multiple reports, while freeing up Controllers for other duties.

In conjunction with the on-board testing of the schedule adherence system, Intracom received and displayed the first deviation reports from test buses in April 2005. These reports accurately indicated the amount of schedule deviation for each bus following an assigned route/run. *Figure 32 shows the Intracom user display of schedule exceptions.*



Bus 571, on run 55-10 is 6 mins, 23 secs late

Bus 229, on run 10-2 is 8 mins, 10 secs late

Figure 32 Intracom schedule exception display

At this point Intracom was capable, if it were in a production environment, of passing the real-time delays to Winnipeg Transit's existing traveler information systems, or future applications such as stop level displays, yet to be developed. This then represented the successful completion of what was a pillar Project milestone.

5.9 Text Messaging

The Project goal for text messaging was the ability to communicate with Bus operators through the use of text messages which could be displayed by the on-board DIU, as an alternative to voice only communication. This capability is particularly useful for information that is:

- confidential or sensitive, or
- relevant over a extended period of time, or
- applies to many buses/Operators.

Such things as police wanted person descriptions, route detours and policy reminder announcements are a few examples.

Another advantage of text, over voice, is that a bus can receive and retain a text message even when the Operator is not on-board, or otherwise pre-occupied, at the time. This ensures better dissemination of information.

The DIU was designed to normally operate on the "home" page, where the call buttons are accessible and current schedule adherence is displayed. Infodev produced the DIU with an LED that indicates when an incoming text message is being received and then displays a message icon (a miniature envelope) on the DIU screen. This icon remains on screen until the Operator uses the DIU menu to access the Message screen and read the message. Messages can be retained in the DIU for various lengths of time, dependant on how defined, or memory available. Most will contain an expiry time imbedded in the message. *Figure 33 shows the DIU home page with a message icon displayed.*

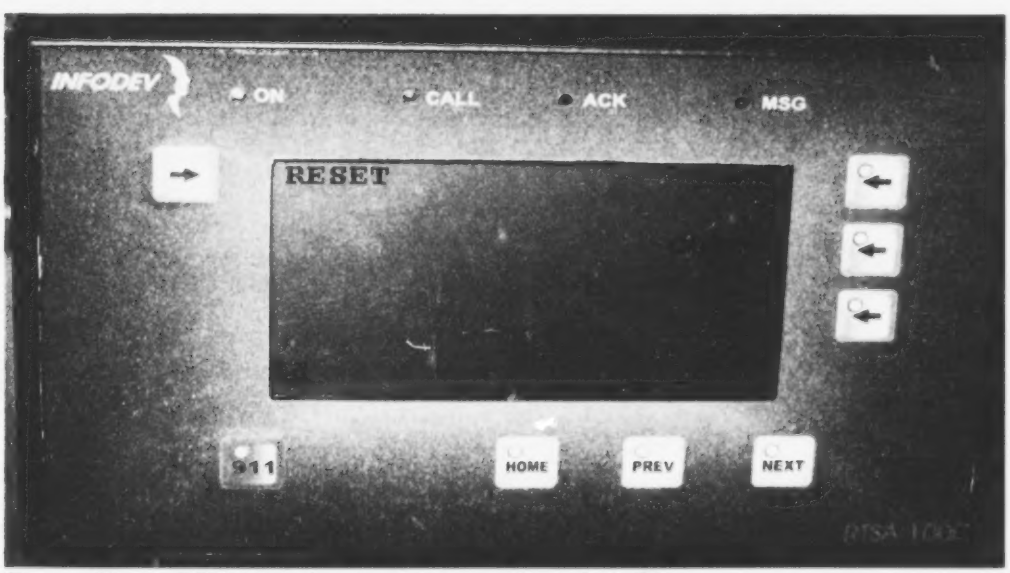


Figure 33 DIU incoming text message "envelope" icon

The overall Winnipeg Transit project approach included the ability to do two-way text messaging, or in other words, the ability to send a data message from Control to a bus or from a bus to Control, or to another bus, via Control. This spans a number of functions. It could be necessary to send Operators text messages requiring a response, such as "Yes" or "No" or "Acknowledged". Or a Bus operator could use the DIU to report information for statistical purposes only and not requiring any action, for instance, mobility devices or strollers carried and/or bike rack usage.

Additionally, an important need was a means for one Operator to quickly notify another Operator when there are passengers wanting to transfer to a bus that is just ahead or across the street. Although voice communication was an option for this, it would be impossible to limit its use to this purpose and therefore text was seen as more controlled solution, minimizing demands on the existing radio channel capacity. So bus-to-bus text message "Transfer Passenger" notification was another system requirement.

Intracom was designed with various features to support one-way and two-way text messaging. Outgoing text messages can be composed by Controllers from a drop down list of template messages, or from free form text. *Figure 34 shows the Intracom message composition user display*

Intracom also has automatic text-related functions. Incoming text messages, such as message acknowledgements or passenger statistics, can be logged in a database and retrieved or reported on later. Text message replies can be sent in response to requests for information from buses, without the need for Controller involvement. A good example is Transfer Passenger requests. Here Intracom can quickly relay a message to a Bus operator to watch for a transferring passenger from another bus, at a certain location and time.

Testing of text messaging began in February 2005, with very short free form text messages sent from Intracom to a test bus. These tests utilized the Infodev BSU and took place while other radio traffic was occurring between the Ferritronics BSUs and other buses. Longer messages were often disrupted, whether due to this competing traffic or other radio interference. Infodev undertook to use smaller "packets" of data, sent in series, to overcome this problem, but these tests in March 2005 met with only limited success. It appeared at this point that the synchronization between the Infodev BSU and on-board controller needed to be improved to handle long data messages. For this reason, and until this could be done, attention turned to using message templates to reduce the amount of actual data to be sent.

Message templates were initially developed for two examples, one a Transfer Request and the other a "Trade Off", which is a term used to describe replacing one bus with another because of a mechanical problem or other reasons. These template messages have certain pre-defined text, which resides in the DIU and Intracom. Other fields are provided for the insertion of bus number, meeting location (normally a time point) and time. The message type is identified by a number, recognized by the DIU. The only data actually

transmitted therefore, is a short string of alphanumeric characters capturing this information. This shortens the length of time for the message to travel and improves the chances of a error free message being received and decoded by the on-board components.

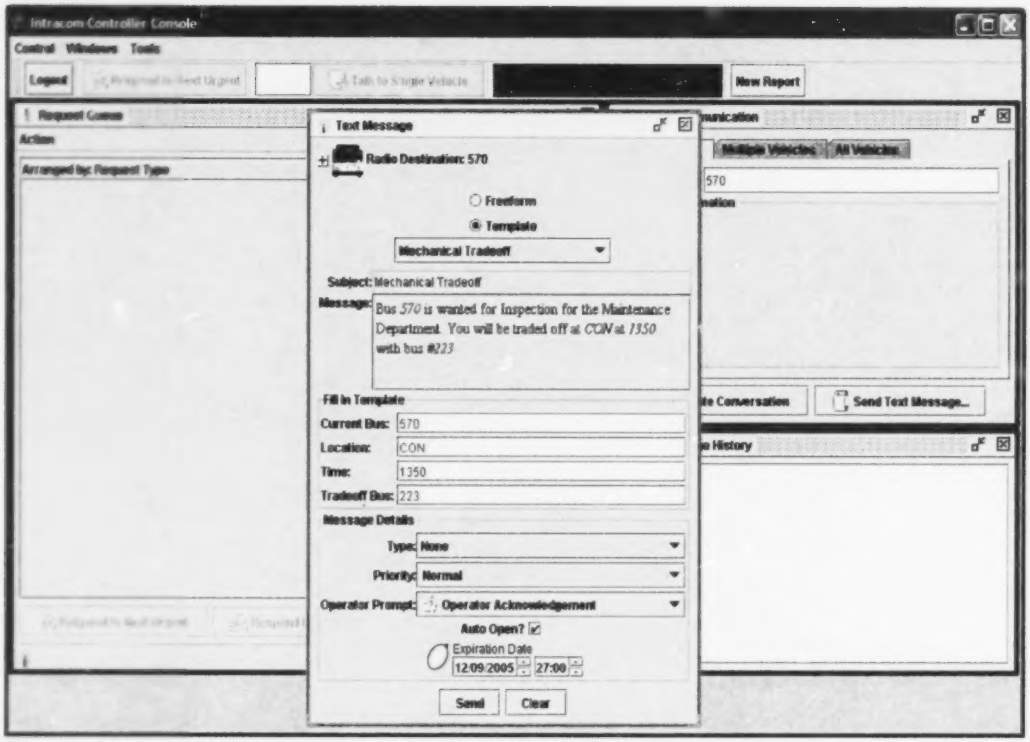


Figure 34 Intracom message composition window

Templates can be developed for any number of scenarios, accessed through a drop down menu in Intracom and user-managed. Similarly, this identical approach will later be used to send Transfer Requests and statistical reports from buses to Control. Only a message type, and if applicable, bus or route number desired, GPS coordinates and schedule deviation need be sent.

Tests of the message templates took place in April 2005, with repeated and reliable transmissions of Transfer Request and Trade-Off messages from Intracom to buses in the field. This marked another major achievement in the development of a communication system that supports advanced functions. *Figure 35 shows a DIU displaying a text message.*

Figure 35 DIU displaying a "Transfer Request" text message

6. RESULTS

6.1 Vehicle Location, Schedule Adherence and Reporting

The existing GPS components of the APC system had already demonstrated that vehicle location could be determined within a few meters accuracy. For real-time application in this Project, the GPS data (latitude, longitude, speed and heading) will be imbedded in the data preamble coming from the bus during voice calls with the Control Center. This information can then be processed by Intracom and presented to Controllers in various ways.

For performing real-time schedule adherence on-board each bus, the data logger contains all run schedules and is assigned to the appropriate one by RF or the radio system. The data logger is interfaced to the GPS receiver, DIU and bus odometer. The schedule adherence system software, operating on the data logger, takes these sources of information, applies an algorithm to compare them and calculates a schedule deviation from the planned itinerary. The system determines *actual* deviation at the defined timing point locations along the route, while at intermediate points it provides *predicted* deviation based on the relative progress of the vehicle over time and distance.

Schedule deviation is expressed in minutes and seconds, either as a negative number for lateness or a positive number when ahead of schedule. This value is constantly displayed to the Bus operator on the DIU to assist him/her in adjusting to conditions, to the extent possible, and operating as close as possible to zero.

The schedule adherence software has parameters defined for automatically reporting deviations exceeding these values to the Control Center via the radio system, where the new Intracom system can process and display these.

The schedule adherence system was tested extensively in regular service during the spring and summer of 2005. There were many revisions to the software during this time, as issues were identified. Overall, however, the system performed extremely well and was found to be a very accurate in calculating the real-time schedule performance of the vehicle. The use of timing point coordinates for verifying actual deviations, combined with predictive deviation along the way, was effective. Operators found the format of schedule feedback on the DIU very helpful and felt that it would positively contribute to maintaining their schedule. The use of GPS technology in this very meaningful way was in itself exciting and interesting to Operators and supervisory staff. The automatic reporting of delays was appreciated by most Operators, as it lessened the burden on them at times when they could be busy. The automatic reporting of being ahead of schedule was met with some apprehension, however, as Operators are aware this is generally an unacceptable practice.

It was demonstrated that Intracom could receive accurate deviation reports that reflected ongoing (versus momentary) schedule exceptions worthy of being brought to the

Controllers attention and/or used to update Winnipeg Transit's existing traveler information systems. These deviations were regularly updated until the deviation fell back within tolerance.

Within the scope of the larger Winnipeg Transit project, these parameters will be changeable dynamically, via a radio data command from the Intracom system. This will allow the volume of deviation reports from buses to be controlled, in the event of conditions causing many or all buses to be experiencing delays. This may be necessary or desirable to maintain radio channel capacity if and when all buses are equipped with this system. In this way, buses could be told to only report delays exceeding some greater threshold, or conversely, report delays less than the new threshold by a defined amount.

Performing on-board schedule adherence using GPS at the timing point level provides sufficient accuracy for supplying supervisory staff and customers with real-time schedule information about current service. However, for some applications it may be necessary to take the level of detail down to the bus stop level. For instance, to provide on-board Next Stop announcements/displays it may be necessary to know precisely, via GPS, when a bus reaches individual bus stops, or has just left a bus stop, in order to give passengers accurate enough information. Another issue is knowing fairly immediately if for some reason a bus is operating off route between timing points, mainly in the event there is some emergency occurring e.g. a high jacking or hostage situation and the Operator is unable to use the radio system or even the silent alarm feature. This would mean also including GPS coordinates for each bus stop in the compressed on-board master schedule, which would increase the file size. Preliminary work by Infodev suggests that this may be very manageable though.

6.2 Schedule Compression and Loading

The fundamental concept within the Advanced Transit Communication and Location System Project was to perform the real-time schedule adherence calculations locally on-board each bus, and only report the exceptions from schedule to the central Control Centre system. This would reduce the data load on the radio system (and required investment in capacity and/or infrastructure), compared to the more traditional approach of vehicles simply reporting their GPS location every minute (or less) to a central computer and doing the schedule adherence determination there.

In order to do this, a method of placing the schedule file on-board the bus for its assigned service had to be found. This could be done prior to the bus leaving the garage, but this would not provide flexibility to reassign the bus in the field, if the need arose, since it would not have any other schedule data on-board for other routes/runs. The chosen approach, therefore, was to place a complete master schedule for *all* runs on-board *every* bus. To limit the amount of on-board memory required and the time to transfer what is a fairly large file, Infodev undertook to use a data compression algorithm to shrink the file size.

Through compression, a complete schedule booking was then reduced from 3.2 MB of data, to just 35 K. After overcoming some small exceptions related to interlined runs containing work/school/industrial trips, the compressed schedule file was found to be 100% accurate.

Each of the 10 buses being used in the Project already were equipped with a data logger, which is a custom microprocessor used to support the Infodev automatic passenger counting system on these and 63 other buses. The compressed schedule file would be loaded onto the data logger, where it could be queried by the DIU for individual runs, and these would then be unzipped for use in conducting schedule adherence. It was desirable to do this several days before the effective start of the schedule period, in order to avoid having to update all buses in a few hours and allow time for any system difficulties. The data logger would therefore need the memory capacity to store not only the current booking, but also the upcoming booking. The current data loggers do not have that amount of excess memory because of the pre-existing APC application, but Infodev plans to release a newer version with more than ample capacity for this and other uses.

The schedule loading was initially performed using the existing infrared transceivers on these buses and those in the garage that were again associated with the APC system. Uploads occurred as the test buses were serviced, with the compressed schedule file successfully transferred in just several seconds.

Next came the development of an automatic mechanism to tell each bus what run it is assigned to before leaving the garage. Because of logistical limitations with IR, work began with the use of spread spectrum Radio Frequency modems in the 2.4 Ghz band. These provide approximately 1 km line of sight coverage, which would allow the large transit complex to achieve complete coverage, indoors and out, with just a few RF modems strategically mounted. After installing an RF modem in one bus and one in the garage, and linking these to the other on-board components and the Winnipeg Transit backend network, it was immediately demonstrated that data could be uploaded or downloaded to the bus in the same way as IR, but without the need for precise physical positioning. Buses could now be given their daily run assignments before leaving the property from any area of the complex. Additionally, it was also demonstrated that the complete compressed schedule could be uploaded to the data logger using RF instead of IR. This will make the need for IR unnecessary, both in the present project and for APC use, if desired.

Finally, the ability to assign or re-assign a run to a bus already out in the field was addressed through the new on-board radio system, coupled with a new message type or command generated by the Intracom system. Standby buses and buses replacing other defective units, can be set remotely to a certain run from anywhere within radio coverage.

6.3 Radio Integration and Performance

The starting point of this project was the need to replace the 25-year-old radio equipment in use at Winnipeg Transit with modern hardware and software that could provide voice and data communication functionality and coverage that met or exceeded existing system capabilities. In addition, the architecture of the new radio system was to integrate with the existing information systems, but which could accommodate future applications requiring additional data communications (for example AVL).

The results of the prototype development were very positive. Infodev was able to design and build a replacement on-board radio control board, first as an analog unit and later using digital signal processing technology, which in both cases replicated existing communication functions, but which could also support new system features through software modification. The first generation analog model worked with the existing GE radios. Then the subsequent DSP version was interfaced to a new, standard Motorola radio. Both of these units were much smaller in size than previous equipment, making replacement installation very easy.

The new driver interface unit was similarly configured to initially support existing communication functions, but fully expandable for future advanced functions. Once in place, the three new on-board components (controller, radio and DIU) were able to seamlessly replace the existing equipment and function as do any other buses in Winnipeg Transit's 535 bus fleet. City-wide coverage was maintained and existing voice call types, both to and from buses, proved reliable. The new DIU display was more user-friendly than the old "four button" set up. The silent alarm function was improved through experimentation with a modern hands-free microphone, enhancing the range of sound detection during threatening on-board situations.

An overheating problem with the on-board DSP controller was experienced during extremely warm summer conditions, causing signal drift to occur and corrupting communications, however, a temporary solution was to increase the ventilation of the unit by removing the top cover. Subsequent refinement of the DSP design will be needed to find a permanent solution to this issue.

The final aspect of the radio system replacement was the development of new base signaling units for the two radio tower repeater sites. These were of identical vintage to the on-board equipment, and were similarly obsolete and unable to support new data applications. Infodev was able to approach the re-design of the BSU based on the development of the DSP controller, which in many ways do the same things, coding and decoding data. In doing so, it was decided to not build a new BSU which replicated the old and could support existing radios/controllers, but rather to create a design that maximized synchronization with the new DSP and which could support new message types. The existing BSU's would continue to support communications with the older equipment until such time as a complete system conversion could take place.

In trials, the new BSU's were reliable in processing existing message types with the test buses outfitted with the new on-board radio equipment, as well as for advanced functions of processing schedule deviation reports and text template messages. For longer, free form text data, the BSU and DSP controller had significant difficulty in the analog to digital coding/decoding of the message and the resulting errors would corrupt the transmission. This appeared to be a problem related to slight differences in the internal signal processing and re-synchronization between the BSU and DSP. This lack of harmony will also be needing resolve in the long term to enable effective text messaging, not limited by templates.

6.4 Intracom and Text Messaging

The development of the new Intracom system has provided the necessary support to the on-board radio and schedule adherence system for deviation reporting and subsequent manipulation of this data. It will also fully support one-way and two-way non-verbal messaging with and between buses. These were the key Project deliverables.

Intracom is user friendly, offering Controllers advanced graphical displays, and enhanced radio communication and incident management features to improve productivity and effectiveness of regulating on-street operations. The design and construction of Intracom addressed shortcomings with the reliability of the existing CONTACT system and should ensure basic radio communications can continue under virtually all circumstances.

During testing, Intracom demonstrated the ability to:

- initiate voice communication with the test buses
- receive incoming calls from test buses
- receive schedule deviation reports
- create and send text message templates
- create and send free form text messages.

As has been discussed, the only difficulty experienced was with longer free form text messages, which is not an issue with Intracom, but rather with the analog to digital decoding processes of the on-board DSP controller and the new BSU's. These need refinement and better re-synchronization routines to harmonize the two devices.

However, for real-time schedule adherence, the development of Intracom contemplated more than simply receiving the raw deviation reports from busses and passing them to other back end systems, without consideration of the relevancy of this information to customers. For instance, if a bus is currently running 10 minutes late, should customers traveling an hour from now be advised that their bus will be late? In the next 60 minutes the bus may be back on schedule, or further behind, and this can change frequently. It may mislead customers to think they should arrive at the bus stop later, only to potentially miss their bus. It may also be confusing for customers to see a constantly changing arrival time, whether viewing this at a stop level display or via the internet.

The closer a bus is to arriving at a particular stop or stops, the more reliable becomes the actual or predicted schedule deviation coming directly from the bus. The greater the distance and time to reach future stops, the more things that can change in the interim and the less reliable the raw incoming deviation reports.

For this reason Intracom is being designed to take the incoming deviation information from a bus or many buses and consider other inputs that may be available, such as service frequency, weather, traffic volumes, and road conditions. This information will be used to better predict the schedule adherence that will exist at points in the future and how far into the future to do this. The resultant real-time transit schedule information that is released to the various traveler information sources will then be more reliable, meaningful and understandable for customers.

Intracom has also been conceived as an intelligent tool for conducting service modelling and service visualization when wide spread disruptions to service are occurring, causing re-routing, delays and service cancellations. A typical example in the Winnipeg climate is a snow storm or blizzard. The sheer number of buses off schedule, and the uncontrollable conditions causing this, can completely overwhelm the ability of the Control Centre staff and field Inspectors to do anything effective about it, even if they had a clear and complete picture of what is happening, which they don't. Busses wind up operating in platoons, resulting in large gaps in service frequency. Service is missing on some routes/legs, and in some areas, while buses elsewhere are under utilized.

Intracom will have the ability to take all of the incoming schedule deviation reports and perform an analysis of what is actually happening on the street and recommend solutions to adjust service that will assist Controllers and Inspectors in returning to more normal operations sooner. Intracom will have that complete picture and be able to visualize a plan to restore regular operations. The usual techniques for doing this, such things as changing service frequencies, shortening the run for some or all buses, moving buses to other routes, and switching Operators between runs, can be presented as a complete "service restoration matrix" to Controllers, allowing them to easily view and choose options. Text message functions will complement this function, so that Operators and Inspectors can be quickly notified of actions to take. The communications system, as already built, will allow Intracom to re-assign busses i.e. the on-board schedule adherence system, to other runs.

So Intracom, once fully developed, should be a powerful, leading edge application for managing urban transit service delivery and is expected to profoundly improve Winnipeg Transit's response to major events. Completion of the system, and other related re-development of other systems, is expected in 2006.

7. CONCLUSIONS AND FUTURE PLANS

7.1 Prototype Demonstration

The primary objective of the project was to develop and test a transit communications system that included an AVL capability and that autonomously performed schedule adherence calculations locally on-board each vehicle and transmitted information for only the buses that are not operating within a designated tolerance of the planned schedule. This "smart bus" platform was successfully developed and demonstrated as the foundation for the implementation of a range of new ITS applications supporting transit operations, planning and customer service functions.

Infodev successfully developed modern new hardware and software to replace Winnipeg Transit's aging and obsolete on-board and base signalling radio equipment and produced a flexible, user friendly driver interface. These supported existing communications, but more importantly facilitated the development of the on-board schedule adherence system. All of these components have provided reliable service in testing.

The prototype system supports GPS-based location reporting of buses during all radio calls. Intracom can graphically display this using mapping tools. This will assist in responding to emergencies where it is important to know the precise location of a bus, as well as its speed and direction of travel.

The schedule adherence system has achieved the goals that were set out. A method for loading the complete schedule for every run on-board all buses was achieved by using data compression to create very portable files that could be transferred via infrared (IR) or radio frequency (RF) spread spectrum technology into the existing Infodev data logger on-board the 10 test buses used in the project. When leaving the garage, RF is then the means by which the run value is set and the schedule files unzipped for use in conducting real-time schedule adherence. For buses already out in service, Intracom and the bus radio system, were also developed to do this. This approach provides complete flexibility to re-assign buses while in service to different routes/runs as the need arises. The GPS-based on-board schedule adherence system has demonstrated the ability to accurately determine the real-time schedule performance of the bus and display this to the Bus operator, together with other helpful schedule information. Schedule exceptions beyond set parameters were reported by the system, using the new bus radio components, but with the existing UHF radio channels and infrastructure. The new Intracom system can then display these to the Service Controllers and when desired, pass the exceptions to other existing traveller information systems.

Implementing a system of this nature minimizes the data traffic required to obtain real-time schedule information fleet-wide, and may make it possible to use existing radio channels/frequencies at no additional cost for this purpose. The on-board equipment required can be compact, durable and supplied cost effectively.

7.2 System-wide Implementation

System-wide implementation of the technology developed during the prototype project will proceed in 2007-2008. This will mean replacement of the on-board controller, radio, handset, external microphone and DIU with the new components on all 535 buses. However, prior to full production implementation, Infodev plans to make several design enhancements to improve the issues identified with performance, packaging and durability. On-board each bus it will also be necessary to install a GPS antenna and receiver, an RF modem and a microprocessor. Infodev expects to replace the current data logger version of the microprocessor with its next generation "Gateway" processor, which will have expanded memory capacity, contain both SA and APC software, and incorporate the GPS receiver and RF modem. The Base Signalling Units will also be replaced at both radio tower/repeater sites and will operate in parallel with the existing BSU's until such time as all buses have been converted to the new system.

In moving to fleet-wide implementation, Winnipeg Transit fully intends to incorporate the following functions that were identified and work started during the prototype phase:

- Two-way text messaging between Intracom and buses, including the use of templates and free form text
- Bus-to-bus notification for passenger transfers
- Field supervisor-to-bus communication (voice, text)
- Enhanced DIU functionality
    - schedule adherence display
    - timing point or stop level schedule display
    - additional prioritization of communication requests
    - text message notification, storage and retrieval
    - operator log in
    - flexible configuration

Full development of the Intracom system will complement and support these functions. Intracom will also be structured to address the need for intelligently predicting schedule adherence into the future, using the real-time exception reports from the fleet, but considering factors such as service frequency, weather and traffic conditions. Intracom will also become an important tool for service recovery from major disruptions, by delivering powerful "service modelling" capabilities to Controllers.

Once implemented fleet-wide, the on-board real-time schedule adherence system, as developed, will provide:

- Automatic updating of current schedules information available through existing Winnipeg Transit telephone and internet-based customer information systems
- A continuous display of actual schedule performance to the Bus operator, in order to potentially influence their performance and improve their schedule observation.

- Assistance to supervisory staff regulating transit service and responding to disruptions with current location and/or schedule deviation information for each bus, for an entire route, or for the system as a whole.

The system will also be the "building block" required to support the following ITS functions which Winnipeg Transit intends to implement in the next two years:

- Real-time next bus displays at terminals, busy bus stops and major activity centres
- Interactive schedules information accessible through portable, handheld devices such as cell phones and PDAs.

However, it is recommended that further work be done in order to conduct on-board schedule adherence on the basis of bus stop level detail, rather than just at timing points. The greater opportunity this would provide for determining the precise physical location of the bus would then support several other advanced applications planned:

- On-board next stop announcements using audio and visual means
- Traffic signal priority measures that could assist approaching buses operating behind schedule
- Automatic and immediate off-route notification to central Control

Winnipeg Transit's database already contains the GPS coordinates for all 5000 bus stops and has information systems that can supply the stop level schedule times. Infodev has done enough preliminary work to indicate that it should be quite feasible to create a compressed master schedule file at the bus stop level that is still small enough to be transferred easily and stored on-board. It is not expected that this level of detail will significantly change the accuracy of calculating schedule adherence. Rather it will allow the on-board system to trigger automatic messaging functions within a few meters accuracy using global positioning, more reliably than by relying on distance and dead reckoning since passing the previous timing point, which could be several kilometres away. For instance, a next stop announcement is ideally made just after a bus pulls away from one bus stop enroute to the next.

From a system performance point-of-view, the ability of the existing radio data channel to handle all the data requirements associated with the schedule adherence system, plus support all of the various messaging functions, will not be fully known until system implementation is completed. It may be that during busy periods when many delays are being reported, that the capacity of the single data channel may become overwhelmed. In anticipation of this, the new system was designed with the ability to regulate the volume of incoming deviation reports by dynamically changing the on-board reporting parameters. Beyond this, it may become necessary to make system changes in order to utilize one or more voice channels for data transmissions, which is possible, or to seek a license for an additional channel(s) from Industry Canada.

In conclusion, the total system, incorporating on-board schedule adherence, text messaging and notification functions, real-time customer information and advanced service control tools, should enable Winnipeg Transit to deliver high quality transit services that are more reliable, convenient and relevant. The system will be the launch pad for delivering new ITS applications that can help make transit services faster and safer and offer more information options to customers.